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AN ANALYSIS OF THE INTERNATIONAL GREAT LAKES LEVELS BOARD REPORT ON REGULATION OF GREAT LAKES WATER LEVELS

Shoreline Property and Recreation

Water Resources Management Workshop
and
Lake Superior Project

University of Wisconsin Madison

September 1976

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Wisconsin Coastal Zone Management Prog.

AN ANALYSIS OF THE INTERNATIONAL GREAT LAKES LEVELS BOARD REPORT ON REGULATION OF GREAT LAKES WATER LEVELS

SHORE PROPERTY AND RECREATION

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ACRONYMS CITED IN THE TEXT

Basis-of-Comparison (BOC)
 Engineering News Record (ENR)
 International Great Lakes Datum (IGLD)
 Low Water Datum (LWD)
 Storm Water Level (SWL)
 Probability Damage Function (pdf)

International Great Lakes Levels Board (IGLLB) of the International
 Joint Commission
 Office of Business Economic Research Services (OBERS)*
 U.S. Army Coastal Engineering Research Center (CERC)
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I. SHORE PROPERTY

INTRODUCTION

Appendices C, Shore Property, and D, Fish, Wildlife and Recreation, of the International Great Lakes Levels Board (IGLLB) report discuss the effects of lake level regulation on shore property. The United States Shore Property Subcommittee consisted of personnel from the U.S. Army Corps of Engineers, Department of the Interior Bureaus of Outdoor Recreation and of Sport Fisheries and Wildlife, the National Oceanic and Atmospheric Administration, and the Environmental Protection Agency. This group analyzed the effects of regulation on erosion and inundation, marine structures, water intakes and sewer outfalls, fish, wildlife, recreation, and water quality. The following sections evaluate the subcommittee's conclusions on erosion and inundation, and recreation.

The method described in Appendix C is not a precise determination of erosion and inundation damages. These damage values can never be estimated with certainty. Rather, the method provides a means for measuring relative damages, i.e., the most probable damages resulting from the base plan versus the most probable damages resulting from a specified regulation plan. Thus, the method conforms well with the standard benefit evaluation techniques for federal flood control projects.

Erosion and flooding damages associated with high lake levels concern most residents of the United States' Great Lakes shores. The IGLLB analysis indicates that a reduction in extremely high levels on Lake Michigan, Huron, St. Clair, Erie and Ontario through two proposed regulation plans, SO-901 and SEO-17P, could yield estimated average annual benefits of \$600,000 and \$7,771,000, respectively, to the United States shore of these lakes. These amounts represent a sizable proportion of the estimated United States benefits from either of these plans (38% and 77%, respectively). Plan SO-901 would cause approximately \$110,000 of average annual flooding and erosion losses to United States shore property owners on Lake Superior. Although the IGLLB's conclusion that either of these plans would produce net benefits to Great Lakes shore property owners appears to be valid, the University of Wisconsin-Madison, Water Resources Management (WRM) Workshop analysis of Levels Board data on regulation's impact upon erosion and inundation indicates that losses to Wisconsin residents on Lake Superior may exceed the estimated benefits to Wisconsin residents along Lake Michigan, if plan SO-901 is permanently enacted. Comparison of the Canadian and United States methods of estimating erosion and flooding losses does not reveal any major inherent biases in their results. Both analyses are primarily useful in only qualitatively estimating the effects of regulation plans.

The estimated benefits to recreation beaches of slightly lowering summer lake levels under plans SO-901 and SEO-17P are important components of the projected economic gains from these plans. Users of Lake Michigan beaches would benefit most from either of these plans. Although the IGLLB may have overestimated the economic gains to beaches from regulation, increased beach acreage is an important product of these proposed regulation plans and deserves recognition. Plans SO-901 or SEO-17P will probably have only a minor impact on marine structures.

II. THE LEVELS BOARD METHOD OF ESTIMATING SHORE PROPERTY LOSSES ON U.S. SHORES FROM LAKE LEVEL REGULATION

INTRODUCTION

In analyzing shore property damages associated with lake level regulation plans, the IGLLB related water levels to flooding and erosion losses. Water levels (stage)-damage curves were developed which integrated each month's highest water level for May 1951 through April 1952 with the dollar amount of damages which occurred in that year. The IGLLB incorporated data on future land uses and values with assumptions on the physical protection of the shoreline to estimate the average annual damages which could be attributed to a change in regulation.

For a more complete understanding of the method involved in the estimation of shoreline damages which are associated with changes in regulation, this section is divided into six main subsections. Each subsection contains a description of the IGLLB procedure and a series of comments designed to highlight the most critical parts of the analysis. Where possible, suggestions for alternative methods and further research are made.

A. SUMMARY OF EROSION AND INUNDATION METHODOLOGY

To evaluate the effect of lake level regulation on erosion and flooding losses suffered by shore property owners, the IGLLB used the following method:

- The IGLLB followed the method developed in a 1965 Army Corps of Engineers study of Lake Erie shore damages. This study related the monthly ultimate water levels (1951-1952) with an adjusted estimate of the damages which had been recorded for that year. The curve $D = 121.9(S - 570.60)^{2.17}$ was accepted as a close approximation of this relationship; D equals the damages per month per mile and S is a monthly ultimate water level on a Lake Erie reach.
- In the process of applying this curve to a single reach and adjusting the curve so that it reproduced the total estimated damages at 1966 conditions, the IGLLB concluded that the curve could be drawn as a straight line on log-log paper. The IGLLB then developed a stage-damage curve for each reach which reproduced the 1952 damages adjusted to 1966 conditions.
- The IGLLB then wrote a computer program which assigned a weight to a damage per month per mile estimate based upon the frequency of occurrence of an ultimate water level under the Basis-of-Comparison conditions and the regulation plan.
- Changes in land use, property values, and expected damages were incorporated into an index of change in unit damages per mile. This index varied for each reach and generally increased rapidly in urban areas. The IGLLB applied this index directly to the weighted damage estimates. The estimated losses for 1980, 2000, and 2020 were then discounted at 7% to yield an average annual damage figure.

B. ULTIMATE WATER LEVELS

Two parameters, the highest or ultimate water level and damage per month per mile, define the stage-damage curves. The first step focuses only on the physical data of ultimate water levels. These data are derived and calculated independently of the damage estimates. Because flooding and erosion losses increase with higher water levels, the United States section of the IGLLB estimated ultimate water levels for each of 36 designated reaches of the United States shore (Appendix A, Figures 7 and 8). This approach followed the method developed earlier by the U.S. Army Corps of Engineers (1965). Calculation of these levels was used not only to define stage-damage curves using the 1951-1952 damage estimates, but also to predict losses through the study period, 1972-2022. As defined by the IGLLB, the ultimate water level is the highest point on a shore or protective structure that the water level reaches during a month. It equals the sum of the undisturbed water level, wind or storm setup, and the wave runup (Figure 1). The IGLLB shore damage computer program computed one ultimate water level per reach per month. Because of their importance, the calculation and use of ultimate water levels is explained below and a sample calculation is found in the appendix (Appendix A, Calculation A).

To correlate the 1952 damage data the IGLLB identified 36 reaches on the United States shores and defined the monthly ultimate water levels during May 1951-April 1952 on the basis of average reach conditions. For a given reach the storm water level, or sum of the undisturbed water level and wind setup, is the maximum instantaneous elevation at the nearest gauging station. There are 15 gauging stations within the 36 reaches. This maximum instantaneous elevation was recalculated to Basis-of-Comparison (BOC) conditions (Appendix A, Calculation A). Then wave runup, which is a function of beach slope, wave period, and wave height, was calculated (Equation 2). Runup was added to the storm water level to get ultimate water level (Equation 1),

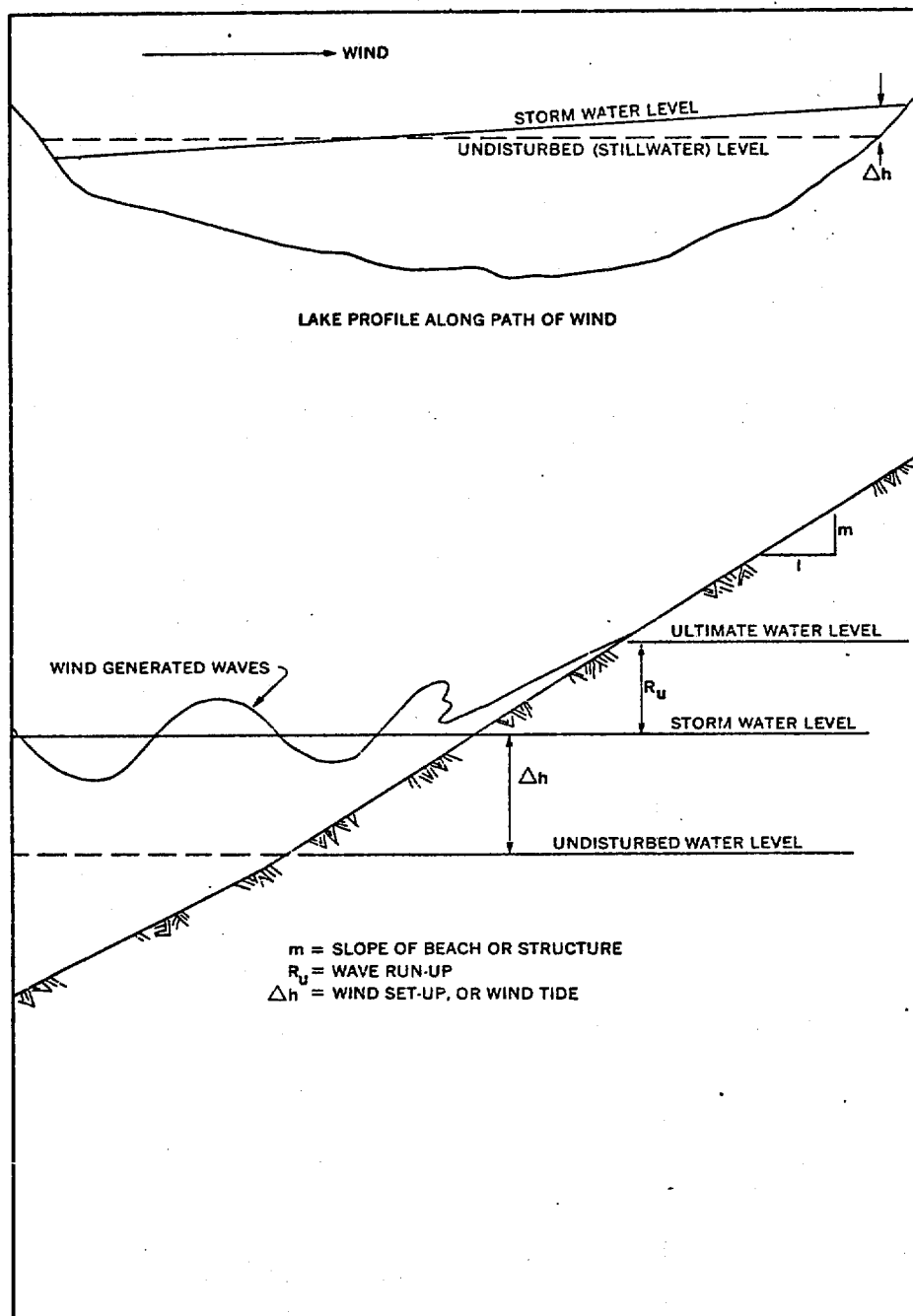
$$R_u = 2.3mTH^{0.5} \quad (1)$$

$$UWL = SWL + R_u \quad (2)$$

where UWL is ultimate water level, SWL is storm water level, and R_u is wave runup, m is the representative beach slope, T is the wave period, and H is the wave height.

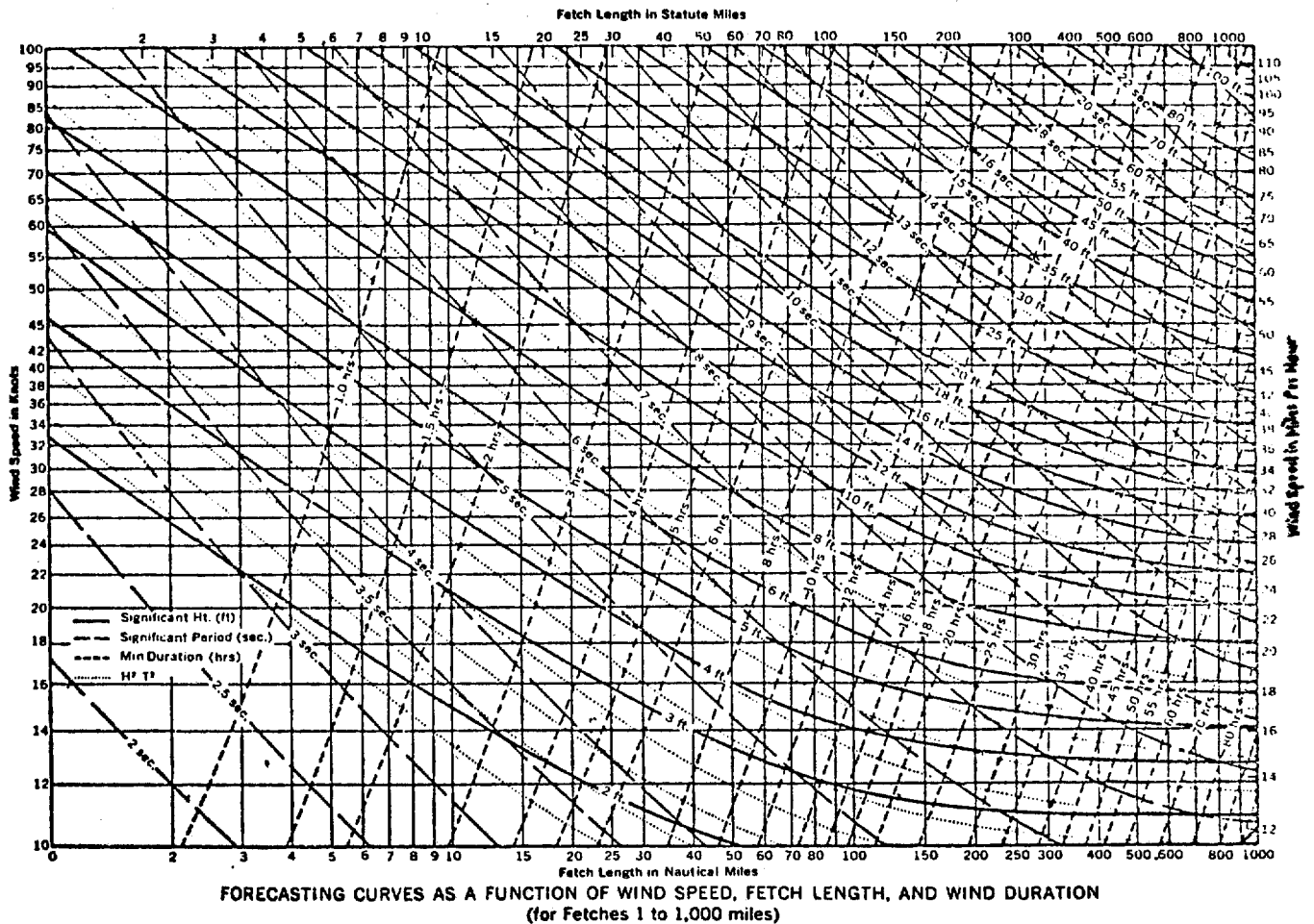
The IGLLB derived representative beach slopes for every reach (Appendix A, Table 14). Since wave periods and heights are determined by wind speed, fetch, and duration of the wind period, the IGLLB applied average wind velocity and direction data from nearby weather stations (16 of them within the 36 reaches) and equivalent fetch distances for every reach (Appendix A, Table 14) to deep water wave forecasting curves compiled by the U.S. Army Coastal Engineering Research Center (CERC) (Figure 2). The forecasting curves predict the maximum deep water wave height, H_o , and associated period, T , for the storm under consideration. The wave period from these curves was used in the runup equation (Equation 2), because, unlike wave height, wave period is only slightly affected by shoaling water (U.S. Army Corps of Engineers 1965, p. C-18). Maximum wave height at breaking, H_b , was calculated using Equation 3,

FIGURE 1 DIAGRAM OF STORM EFFECTS ON WATER LEVELS



Source: IGLLB 1973, Appendix C, p. C-8.

FIGURE 2 DEEP WATER WAVE CURVES



Source: IGLLB 1973, Appendix C, p. C-34.

$$H_b = \frac{d_b}{1.28} \quad (3)$$

where d_b is the breaking depth. Breaking depth was calculated by subtracting the lake elevation (Low Water Datum, LWD) above the International Great Lakes Datum (IGLD), established in 1955, from the storm water level (Equation 4).

$$d_b = \text{SWL} - \text{LWD} \quad (4)$$

The minimum value of either deep water wave height, H'_0 , or maximum breaker height, H_b , was used in the runup equation.

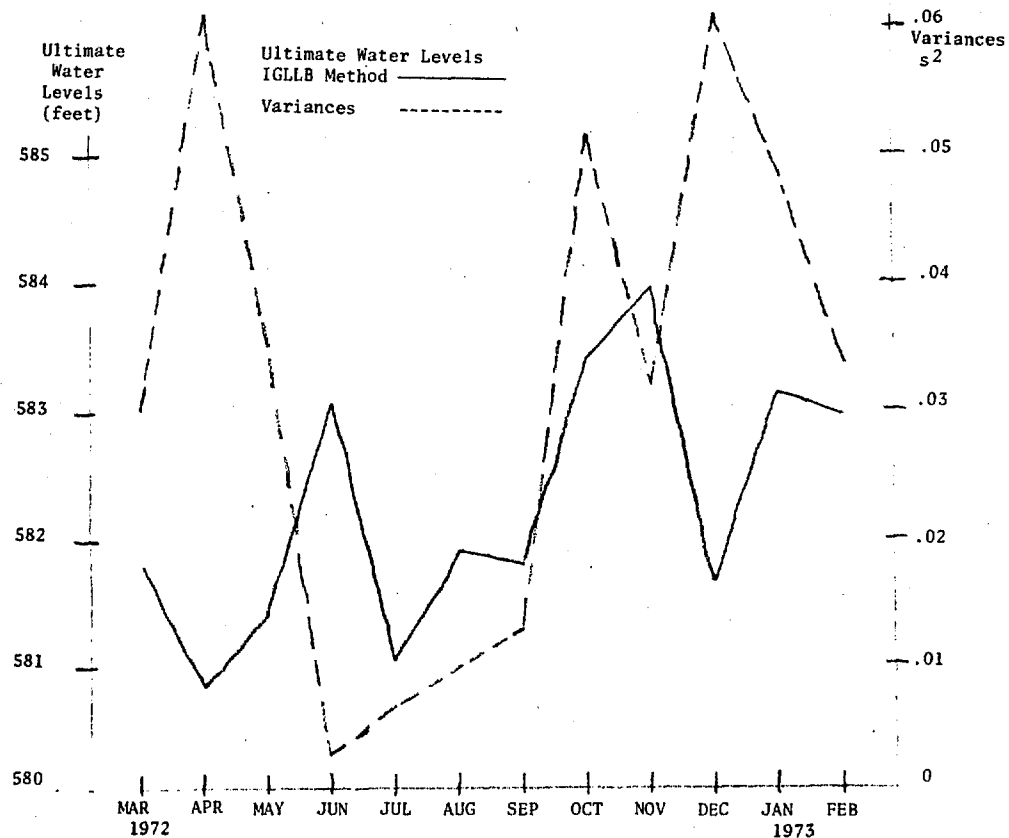
By using a stage-damage curve, both the Corps' 1965 study and the IGLLB accepted the monthly ultimate water calculations as an index of damaging capacity. Both analyses assumed that the shore damages reported in 1952 as a sum could be distributed over the 1951-1952 period based upon the monthly ultimate water levels. Because months with higher ultimate water levels exhibited more numerous and longer lasting high levels than months with lower ultimate water levels, the 1965 Corps report (p. C-23) determined that the stage-damage curve was not linear but rather curvilinear. In effect, higher ultimate water levels cause considerably more damage than lower levels. Thus, the Corps study and the IGLLB distributed the 1951-1952 damage estimates over a 12-month period according to the monthly ultimate water levels for that year.

One ultimate water level per month as an index of damaging capacity. The IGLLB assumed that this procedure would distribute damages such that the stormy months would receive the most damages. While it is generally agreed that most shoreline damage occurs in stormy months, it seems questionable that a single ultimate water level appropriately represents the relative frequency of storms in each month (IGLLB 1973, Appendix C, p. C-25). To check this assumption, the variance of mean daily lake levels about their monthly mean was calculated (Appendix A, Table 15) for the 1972 record of the Milwaukee gauging station. Variance, in this case, is used as an alternative index of monthly storm frequency. Thus, the calculation assumes that day-to-day variations in lake levels are mainly due to passing storms and associated wind setup. Variances are plotted on the same sheet as the ultimate water levels calculated by the IGLLB method for an overlapping one-year period (Figure 3). This plot shows that months with high ultimate water levels are not always the same as those with high variances. If variance of daily mean levels within a month does represent storm frequency, then ultimate water levels do not correctly distribute damages among the twelve months. A better index of damage might be the within-month variance multiplied by the ultimate water level for the month. This index gives equal weight to storm frequency and monthly lake level. Because regulation plans have been designed to change the monthly distribution of levels, inaccurate distribution of damage capacity for each month could result in an improper representation of the relative benefits of a regulation plan.

Another problem with distribution of damages based upon ultimate water levels is that shoreline erosion by waves does not occur when the lakeshores are frozen over. The Levels Board decided that omitting winter months was an unnecessary refinement (IGLLB 1973, Appendix C, p. C-35). However, if shore erosion damages were distributed over 10 months rather than 12, the stormy months would be more properly weighted.

Beach slope estimate. There are two problems with the IGLLB use of beach slope in calculating ultimate water levels: (1) how the IGLLB determined beach slope, and (2) whether the use of an average beach slope to represent an entire reach is appropriate. Because the calculation of ultimate water level is sensitive to changes in beach slope, the method for determining beach slope must be applied consistently on each reach. However, the following examination illustrates inconsistencies in the IGLLB method.

FIGURE 3 INDICES OF SHORELINE DAMAGE: COMPARISON OF ULTIMATE WATER LEVEL (IGLLB METHOD) WITH VARIANCE OF DAILY LAKE LEVELS FOR INDIVIDUAL MONTHS (1972-1973) ON REACH 7004-LAKE MICHIGAN



Source: U.S. Department of Commerce 1972-1973, Great Lakes Levels.
U.S. Department of Commerce 1972-1973, Climatic Observations.

Representative beach profiles used by the IGLLB to determine beach slope were studied for Reach 7003 (Milwaukee to Manitowoc) and Reach 7004 (Waukegan to Milwaukee). The beach slope for Reach 7004 (Appendix A, Table 14) is equal to the average of the slopes of the two profiles indicated for that reach (IGLLB 1966). The slope for Reach 7003, however, is not the average of the three profiles indicated in that reach. Such differences in the method used to determine slope reduce the accuracy of comparisons of damages among different reaches.

A second problem with the IGLLB slope estimate is that by using a beach slope value which represents an average of several shore profiles per reach, the IGLLB method may mask some important erosion effects. On Reach 7004, for example, two representative beach profiles indicate beach slopes of 1:6 and 1:18, respectively (IGLLB 1966). When such a large difference in representative slopes on a reach exists, perhaps the slope used in calculating ultimate water level should be weighted in favor of the slope of the areas which are subject to greatest damage. Thus, the ultimate water level of critical damage areas will be more accurate.

Wave period determination. There is a considerable amount of inaccuracy in the IGLLB methodology for determining wave periods. This inaccuracy is inherent in the methods presently available for hindcasting wave characteristics. Determining wave period from deep water forecasting curves (Figure 2) requires wind speed, fetch, length, and wind duration. Averaging wind speed and fetch over the duration is correct here because of the slow development of equilibrium wind waves (U.S.-CERC 1973, vol 1., p. 3-33). Wind velocities from land-based weather stations were increased by a factor of 1.2 because of reduced friction over water. However, in the Shore Protection Manual the Corps states: "Simplified wave prediction models (Figure 2) . . . , will be accurate (within 20%) about 2/3 of the time" (U.S.-CERC 1973, vol 1, p. 3-20). A sample calculation (Appendix A, Calculation B) shows that a range of $\pm 20\%$ in wave period can result in a 0.5 foot difference in the ultimate water level. Because the stage-damage curve used to calculate damages is sensitive to small differences in ultimate water level, a 0.5 foot difference can change substantially the dollar damages assigned to a storm. Because damages rise exponentially as the ultimate water level increases (see section C), the uncertainty in the calculation of damages for severe storms is much greater than that associated with mild storms.

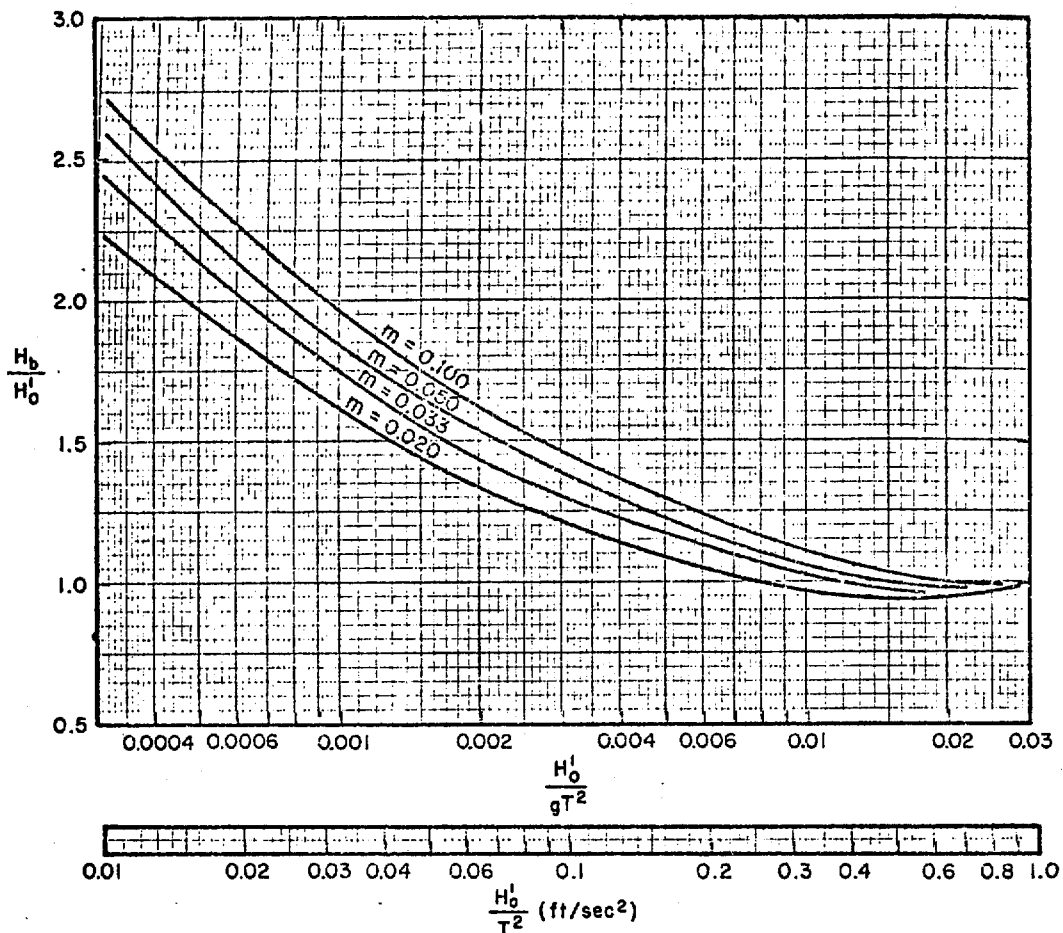
Wave height determination. The IGLLB's method for obtaining wave height (H) is inaccurate for several reasons. First, deep water wave height (H_o) estimates are based on the same hindcasting technique as that used to determine wave period. Hence, the inaccuracy of the calculation is of the same order as that described previously (20% two-thirds of the time). Such uncertainty, however, affects the determination of ultimate water level less than the inaccuracy of the wave period calculation because wave height is factored by its square root while wave period is not (Equation 1).

Secondly, the IGLLB computes maximum breaker height (H_b) by using Equation 3 (IGLLB 1973, Appendix C, p. C-32).

There are two problems with this method. One problem involves the calculation of breaking depth (d_b) and has the effect of underestimating the damages associated with plans which reduce mean monthly water levels. Likewise, the method overestimates damages for plans which raise mean monthly levels. The IGLLB defines breaking depth in Equation 4 where storm water level (SWL) is the maximum instantaneous recorded water level in a month and low water datum (LWD) is a constant elevation assigned to each lake (GLBC 1975, Appendix 11, p. 95). Storm water level is further defined as the recorded mean monthly lake level plus storm setup. A comparison of breaking depth calculation for two like storms (same wave heights and wave periods) occurring at different mean monthly water levels indicates the bias in the IGLLB method. Waves caused by equal storms on the same reach have equal breaking depths despite differences in mean monthly lake levels. However, the example calculation (Appendix A, Calculation C) indicates a difference of over two feet in computed breaking depth and a difference of 0.68 feet in the resulting runup computations. The discrepancy results from the use of a fixed elevation in calculating breaking depth.

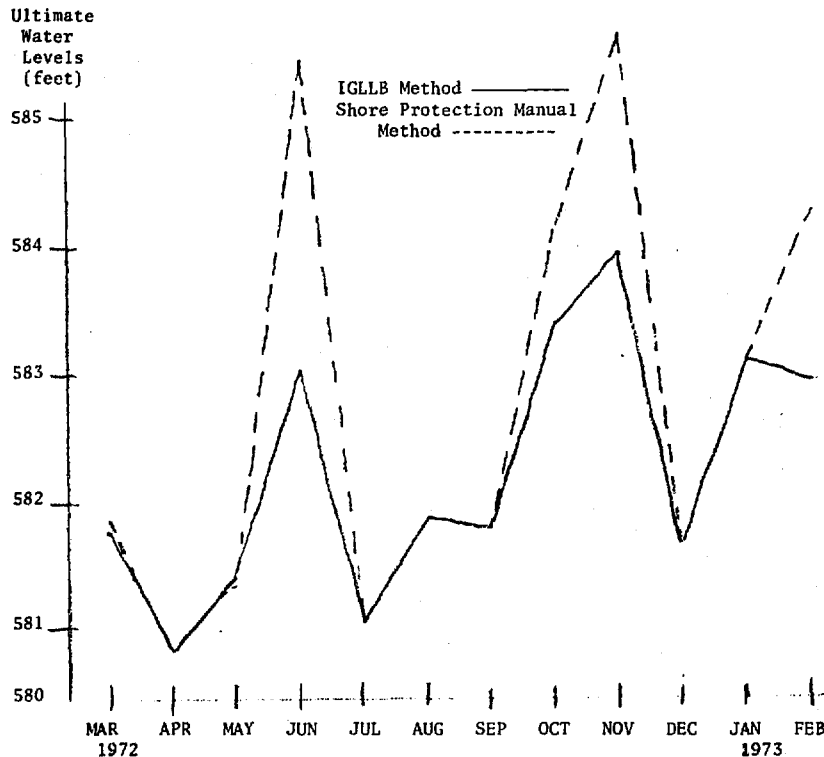
Another problem with the IGLLB calculation of breaker height (Equation 3) results from defining breaker height as being linearly related to breaking depth. According to the Shore Protection Manual (U.S.-CERC 1973, Vol 2, pp. 7-5), a nonlinear set of relationships based on nearshore slope is more appropriate. A sample problem (Appendix A, Calculation D) compares breaker height computed by the IGLLB method with that obtained using the curves shown in Figure 4. The result is that the breaker height computed by using the curves is 275% greater than that indicated by the IGLLB method. Figure 5 compares ultimate water levels calculated by using the two methods to determine breaking depths. Hourly wind data (March 1972-February 1973), from Milwaukee's Mitchell Field was used. Figure 5 indicates that the IGLLB method underestimates ultimate water levels associated with severe storms (June, October, and November). As a result, IGLLB water level damages will tend to be distributed more uniformly throughout the year than the alternative method would indicate. However, annual damages should actually be concentrated, even more so than presently indicated, in a few stormy months.

FIGURE 4 BREAKER HEIGHT INDEX, H_b/H'_0 , VERSUS DEEP WATER WAVE STEEPNESS, H'_0/gT^2



Source: U.S.-CERC 1973, vol 2, p. 7-7.

FIGURE 5 CALCULATION OF MONTHLY ULTIMATE WATER LEVELS FOR REACH 7004 BY TWO METHODS



Source: U.S. Department of Commerce 1972-73, Great Lakes Levels.
U.S. Department of Commerce 1972-73, Climatic Observations.

Summary

There are three criticisms of the IGLLB's calculation and use of ultimate water levels. First, there are inaccuracies which affect equally calculations for Basis-of-Comparison and regulation plans. Uncertainty associated with determining beach slope, wave period and height, and monthly wave climate (damaging capacity) reduces the validity of using the IGLLB methodology to measure relatively small differences in lake levels.

Secondly, the IGLLB computation of breaker height (Equation 3) tends to underestimate ultimate water level (and, thus, dollar damages) when mean monthly levels are lowered. Likewise, ultimate water levels are overestimated when mean monthly levels are raised. Since a general effect of the proposed regulation plans is to lower the higher mean monthly levels on most lakes, the benefits of regulation may be overstated.

Finally, in computing ultimate water levels, the IGLLB uses averages of such characteristics as beach slope and fetch length to determine the effect of regulation on a reach which may actually include many varied physical characteristics. However, lake shore damages tend to occur primarily in a few areas within each reach where economically valuable resources are particularly susceptible to erosion and flooding. If the characteristics of these areas were weighted more heavily in assigning representative figures, damage estimates could be more accurate.

C. DAMAGE ESTIMATES AND PROJECTIONS OF FUTURE LAND USES

The second component of the stage-damage model is the estimate of damages at different ultimate water levels. This appraisal of economic losses was obtained from the Corps' 1952 shore damage survey, an inventory of shoreline uses and values in 1966-1967, and projections of future land uses and values.

1. The Corps' 1952 Damage Survey

The 1952 study provided the IGLLB with estimates of total damages between May 1951 and April 1952 for specified land use types, and the number of miles of unprotected shoreline. In the spring of 1952 under the direction of the Corps and selected state officials (i.e., in Wisconsin, the chief engineer of the Public Service Commission), local officials or community organizations estimated the shore property damages occurring during the high water period of April 1950-April 1952. Although newspapers announced the survey and to whom damage estimates should be sent, the local officials did not hold public meetings nor directly contacted some of the shore property owners. Thus, property owners submitted much data on their own volition. To confirm the figures, Corps personnel checked selected damage areas (U.S. Army Corps of Engineers 1952, p. A-15).

Damages designated as having occurred during the study period, May 1951-April 1952, were one-half of the total reported losses. The survey along Wisconsin's Lake Superior shore included damages on the Apostle Islands and the 150 miles of mainland shore. Total damage estimates included the following elements:

Direct damage

- Damage to existing protective structures
- Cost of protective structures built during the above period
- Damage to improvements on shore property and in water, other than protective structures
- Value of land lost by erosion
- Depreciation in sale value of land in remainder of tract of land, and improvements thereon, because of portion of tract of land being lost by erosion
- Damage to crops or improvements caused from inundation by high lake levels.

Indirect damage

- Cost of emergency fight during extreme high lake level conditions
(Not to duplicate direct damage of the third item on the preceding page.)
- Loss of business or increase in cost of business due to high lake levels
- Loss of wages due to high lake levels
- Increase in cost of rail or highway transportation due to high lake levels.

At 1952 price levels the survey found \$674,000 of damages to private property and \$308,000 of losses to public property along Wisconsin's Lake Superior shore for the year May 1951-April 1952 (Table 1). The 1952 survey estimated the damages (\$37,000) occurring to agricultural and undeveloped lands as well as damages to developed areas.

Compilation of 1952 damage data. Since much of the data on shore damages was submitted in the spring of 1952 at the volition of the property owner, it is likely that not all shore property owners, such as seasonal residents, submitted damage information. In addition, shore residents who did submit damage information may have lacked adequate information to submit a realistic estimate. Currently, the Corps has contracts with several Great Lakes states for the collection of additional shore damage data, which when compiled may be compared with and supplement the 1952 study. Two professionals who are conducting the present shore study in Wisconsin have commented that the 1952 damage survey results appear to be overestimated in comparison to their knowledge of recent high water level damages (Tyschen and Pirie 1975).

2. 1966-1967 IGLLB Shore Survey and Land Use Projections

Between 1966 and 1967 the IGLLB requested Corps district offices to conduct a field survey of shore conditions and to provide projections of future land use and protection. The field survey inventoried shoreline uses, miles of protective structures, critical erosion areas, and general beach and bluff features. This survey did not estimate flooding and erosion losses, partly because of the lower water levels and absence of dramatic damage at this time. Categories of shoreline use included: industrial-commercial, residential, utilities, fish and wildlife, forested and undeveloped, agricultural, public parks and beaches, and federal harbors.

Next, the district offices projected changes in protection and land use type for 1980, 2000, and 2020. This step was accomplished by using Office of Business Economic Research Services (OBERS) projections of population in addition to the judgment of district personnel and other professionals familiar with area development. In general, district personnel assumed that agricultural and undeveloped land would be converted to industrial-commercial uses, residential areas, and parks and beaches. In general, it was presumed that existing patterns of development would continue.

The district offices estimated the number of miles of protected shoreline using the following assumptions (IGLLB 1973, Appendix C, p. C-23; McIntyre 1975):

- All new industrial and commercial property, including federal reservations and harbors will be protected. Reservations do not include Indian lands

TABLE 1 DAMAGE TO PRIVATE PROPERTY ON LAKE SUPERIOR
ONE-YEAR PERIOD FROM SPRING 1951 TO SPRING 1952

Reach of Shore	Direct Damage						Indirect Damage				Grand Total Damage
	To all Property from Inundation	Commercial Property (1)	Residential Property (1)	Agricultural or Undeveloped Property (1)	Utilities (1)	Total	To all Property from Inundation	Commercial Property (1)	Utilities (1)	Total	
Superior Shore, Duluth-Superior Harbor	\$ 130,000	\$ 10,000	\$ 32,000	\$15,000	\$ 16,000	\$203,000	\$ 34,000	\$ —	\$ —	\$ 34,000	\$237,000
Superior Entry to Port Wing	—	15,000	2,000	3,000	—	20,000	—	—	—	—	20,000
To Ashland	3,000	204,000	81,000	10,000	—	298,000	—	2,000	—	2,000	300,000
Apostle Islands	—	3,000	41,000	—	—	44,000	—	—	—	—	44,000
To Wis.-Mich. State Line	—	28,000	32,000	9,000	—	69,000	—	4,000	—	4,000	73,000
Sub-Total Wisconsin Shore	133,000	260,000	188,000	37,000	16,000	634,000	34,000	6,000	—	40,000	674,000
DAMAGE TO PUBLIC PROPERTY ON LAKE SUPERIOR ONE-YEAR PERIOD FROM SPRING 1951 TO SPRING 1952											
Superior Shore, Duluth-Superior Harbor	\$ 70,000	\$104,000	\$ —	\$ —	\$ —	\$174,000	\$ —	\$ —	\$ —	\$ —	\$174,000
Superior Entry to Port Wing	—	—	—	4,000	—	4,000	—	—	—	—	4,000
To Ashland	—	37,000	3,000	61,000	—	101,000	—	—	3,000	3,000	104,000
Apostle Islands	—	—	—	6,000	—	6,000	—	—	—	—	6,000
To Wis.-Mich. State Line	—	1,000	15,000	4,000	—	20,000	—	—	—	—	20,000
Sub-Total Wisconsin Shore	70,000	142,000	18,000	75,000	—	305,000	—	—	3,000	3,000	308,000

Source: U.S. Army Corps of Engineers 1952.

(1) Damage other than inundation.

- All utilities will be protected
- Protection of residential and recreational property occurs when the expected damages equal or exceed the cost of protection (McIntyre 1975)
- Agricultural, forested, and undeveloped lands will not be protected.

Tables 2 and 3 show the changes in land use and the miles of protected shoreline for Reach 7003 from Milwaukee to Manitowoc and Reach 9002 from Sand Bay, Wisconsin to the mouth of the Presque Isle River in Michigan. The St. Paul district developed the projections for Lake Superior, while Robert McIntyre of the Corps' North Central Division in Chicago prepared the estimates of Wisconsin's Lake Michigan shore. Thus, the IGLLB estimated changes in land use and the miles of protected shoreline in every reach. If a mile of shoreline was assumed to warrant protection, it was subtracted from the land base which experiences damages, because the U.S. analysis presumed that protected property would incur no damages during the project period.

Reach definition. The reaches used in the IGLLB study are different from those used in the 1952 survey so that aggregated information from one study cannot be compared with that of the other. For example, the IGLLB reach 9002 extends from Two Harbors, Minnesota to Sand Bay, Wisconsin. However, Sand Bay is located inside the 1952 reach which extends from Port Wing to Ashland. Thus, in order to use the 1952 survey, it was necessary for the IGLLB to retabulate the damages using the original 1952 survey sheets of individual property owners (Carlson 1975). The two studies used different reaches because the 1952 study was designed to tabulate damages according to state, while the IGLLB study designated reaches according to wave and shore characteristics.

3. Estimates of Future Damages Considering Changes in Land Use, Property Value, and Shoreline Protection

The eventual construction of a relationship between water levels and damages required estimates of how dollar damages increase in proportion to property values. As explained above (section C.2), Corps district personnel estimated the changes in land use and miles of protected shoreline (Table 2, Rows A-C). Richard Carlson of the Corps' Chicago district and William Henry of the Buffalo district computed the damages occurring to the different land use categories from the following direct damage estimates of the 1952 damage survey (Carlson 1975):

- Damage to improvements on shore property and in the water, other than protective structures
- The value of land lost by erosion
- Damage to crops or improvements caused from inundation by high lake levels.

The 1952 damages were updated to 1966 prices using the Engineering News Record (ENR) construction and building cost index conversion factors. Carlson and Henry calculated only the damages occurring to those properties not economically feasible to protect which would sustain damage in the future. These computations yielded the 1966 figures for total damages (Table 2, Row F) and unit damages per mile (Row D).

TABLE 2 PROJECTIONS REACH 7003—MILWAUKEE TO MANITOWOC

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	TOTAL	IND. & COMM.	RESI- DENTIAL	AGRI. & UNDEVEL.	PRI. & PUBLIC UTILITIES	PARKS & BEACHES	FEDERAL RESERVA- TIONS
Land Use (Mi)							
1966	79.8	4.0	36.0	26.2	2.0	10.0	1.6
1980	79.8	4.7	37.0	20.6	2.9	13.0	1.6
2000 (A)	79.8	5.5	38.0	11.1	3.6	20.0	1.6
2020	79.8	7.0	39.2	0.0	5.0	27.0	1.6
Protected (Mi)							
1966	9.6	0.6	2.4	0.4	2.0	2.6	1.6
1980	19.7	4.7	4.0	0.0	2.9	6.5	1.6
2000 (B)	28.7	5.5	8.0	0.0	3.6	10.0	1.6
2020	42.2	7.0	15.1	0.0	5.0	13.5	1.6
Unprotected (Mi)							
1966	70.2	3.4	33.6	25.8	0.0	7.4	0.0
1980	60.1	0.0	33.0	20.6	0.0	6.5	0.0
2000 (C)	51.1	0.0	30.0	11.1	0.0	10.0	0.0
2020	37.6	0.0	24.1	0.0	0.0	13.5	0.0
Unit Damages Per Mile (\$)							
1966	39,729	40,559	67,229	4,108	0.0	38,676	0.0
1980	71,830	0.0	114,303	5,728	0.0	65,692	0.0
2000 (D)	170,235	0.0	240,267	9,820	0.0	138,200	0.0
2020	436,410	0.0	514,398	0.0	0.0	297,185	0.0
Index of Change-- Damages (1966=100)							
1966	100	100	100	100	0.0	100	0.0
1980	181	0.0	170	139	0.0	170	0.0
2000 (E)	428	0.0	357	239	0.0	357	0.0
2020	1,098	0.0	765	0.0	0.0	768	0.0
Total Damages (\$)							
1966	2,789,000	137,900	2,258,900	106,000	0.0	286,200	0.0
1980	4,317,000	0.0	3,772,000	118,000	0.0	427,000	0.0
2000 (F)	8,699,000	0.0	7,208,000	109,000	0.0	1,382,000	0.0
2020	16,409,000	0.0	12,397,000	0.0	0.0	4,012,000	0.0

Source: IGLLB 1973, Appendix C, p. C-83.

TABLE 3 PROJECTIONS REACH 9002—TWO HARBORS, MN TO SAND BAY, WI

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	TOTAL	IND. & COMM.	RESIDENTIAL	AGRI. & UNDEVEL.	PRI. & PUBLIC UTILITIES	PARKS & BEACHES	FEDERAL RESERVATIONS
Land Use (Mi)							
1966	106.4	3.5	23.1	62.9	0.0	16.9	0.0
1980	106.4	3.8	23.9	61.2	0.0	17.5	0.0
2000 (A)	106.4	6.6	27.4	52.3	0.0	20.1	0.0
2020	106.4	9.3	31.5	42.5	0.0	23.1	0.0
Protected (Mi)							
1966	3.5	3.5	0.0	0.0	0.0	0.0	0.0
1980	3.8	3.8	0.0	0.0	0.0	0.0	0.0
2000 (B)	6.6	6.6	0.0	0.0	0.0	0.0	0.0
2020	9.3	9.3	0.0	0.0	0.0	0.0	0.0
Unprotected (Mi)							
1966	102.9	1.6	23.1	61.3	0.0	16.9	0.0
1980	102.6	1.6	23.9	59.6	0.0	17.5	0.0
2000 (C)	99.8	1.6	27.4	50.7	0.0	20.1	0.0
2020	97.1	1.6	31.5	40.9	0.0	23.1	0.0
Unit Damages Per Mile (\$)							
1966	10,756	155,700	34,700	523	0.0	1,600	0.0
1980	15,579	234,200	48,200	623	0.0	2,200	0.0
2000 (D)	28,218	346,400	78,800	718	0.0	3,600	0.0
2020	51,133	458,200	129,100	854	0.0	6,000	0.0
Index of Change-- Damages (1966=100)							
1966	100	100	100	100	0.0	100	0.0
1980	145	150.4	139	118	0.0	138	0.0
2000 (E)	262	222.4	227	136	0.0	225	0.0
2020	475	294.0	372	162	0.0	375	0.0
Total Damages (\$)							
1966	1,106,800	249,200	802,300	28,100	132,800	27,200	0.0
1980	1,598,500	374,800	1,152,700	32,100	0.0	38,900	0.0
2000 (F)	2,816,200	554,200	2,158,300	30,600	0.0	73,100	0.0
2020	4,965,100	733,200	4,066,300	28,000	0.0	137,600	0.0

Source: IGLLB 1968.

The IGLLB study then applied 1968 OBERS projections of income or agricultural productivity to the 1966 base damages to derive indices of damage change for each land use category (Table 2, Row E, Columns 2-7). The value of damages was assumed to be directly related to the property value (McIntyre 1975). Projected total damages (Row F) were then divided by the estimated number of unprotected shoreline miles. From the total unit damages per mile the IGLLB derived the index of total unit damages per mile (Row E, Column 1). This index was the basis for the "shortcut" procedure described in section D.2. These estimates of unit and total damages were derived from adjusted 1952 data coupled with projections of increased property value and changing land uses. The figures have no relationship to a particular water level regime. Adjustments applied to the 1952 data are explained below, but the IGLLB developed the data shown in Tables 2 and 3 independently of the ultimate water level calculations. Integration of estimated ultimate water levels and projections of total damages is explained in section D.1.

Property value projections. The use of income projections to predict changes in property value (and, thus, unit damages) appears to be justified. Comparison of increases in per capita adjusted gross income and total adjusted gross income with increases of property value in Wisconsin's coastal counties indicates that percentage increase in income is generally a conservative index of percentage increase in property value (Wisconsin Department of Administration 1974).

Projected damages—residential property value. The index of change of total unit damages per mile (used to project damages for 1980, 2000, and 2020) is sensitive to changes in the index of unit damages in residential property. Reach 7003 (Milwaukee to Manitowoc) and Reach 9002 (Two Harbors, Minnesota to Sand Bay, Wisconsin) were used as test cases for observing the effects of altered input data on the index of change of total unit damages. On Reach 7003 an alternative index of 361 was substituted in place of 765 for the 2020 index of unit damages to residential property (Table 2, Row E, Column 3); 361 is an index of projected percentage increase of per capita income in the Milwaukee Standard Metropolitan Statistical Area (SMSA)* from 1970 to 2020 using 1972 OBERS data. The substitution changes the index of total unit damages (Row E, Column 1) from 1,098 to 660, meaning that the projected damages for 2020 on Reach 7003 may be overestimated by 43%. On Reach 9002 an alternative index of 442 was substituted in place of 372 for the 2020 index of unit damages to residential property (Table 3, Row E, Column 3); where 442 is an index of projected percentage increase of per capita income in the Duluth-Superior Bureau of Economic Analysis (BEA)** district from 1970-2020 using 1972 OBERS data. The substitution changes the index of total unit damages (Row E, Column 1) from 476 to 555, meaning that the projected damages for 2020 on Reach 9002 may be underestimated by 16%. The index of total unit damages is more sensitive to changes in the index of unit damages for residential property than it is to the indices for other shoreland uses because residential property generally experiences more damage than the other categories.

* A county or group of contiguous counties which contain at least one city of 50,000 or more.

** Districts assigned according to the principal center of economic activity in area. Essentially, it includes areas which are more rural than those in SMSA's.

A comparison of the indices of unit damages to residential property on Wisconsin's shoreline with indices provided by 1972 OBERS projections of income from 1970 to 2020 shows that IGLLB projections of residential damages are underestimated on Lake Superior, while they are overestimated on Lake Michigan (except for Reach 7011—Escanaba, Michigan to Green Bay). The significance of these differences is that the shore property benefits of lowering Lake Michigan levels are somewhat overstated while the damages from raising Lake Superior levels are slightly understated (see Table 4). However, the effect of the above differences on the average annual benefit or loss experienced by either shore interest is reduced because of discounting and damages to other shore uses.

TABLE 4 COMPARISON OF IGLLB INDEX OF UNIT DAMAGES TO RESIDENTIAL PROPERTY IN 2020 WITH 1972 OBERS INDEX OF INCOME IN 2020

WISCONSIN SHORELINE		INDICES OF ECONOMIC GROWTH AND SHORE PROPERTY DAMAGE		
Reach	Extent	1968 IGLLB Index	1972 OBERS Index	Approximate Percentage Difference Between Indices
Lake Superior				
9002	Two Harbors, MN Sand Bay, WI	372	410	10 %
9003	Sand Bay, WI Presque Isle River, MI	336	410	20 %
Lake Michigan				
7011	Escanaba, MI Green Bay, WI	320	450	40 %
7012	Green Bay, WI	912	460	-50 %
7002	Summer Island Manitowoc, WI	753	450	-40 %
7003	Manitowoc, WI Milwaukee, WI	765	450	-42 %
7004	Milwaukee, WI Waukegan, IL	770	400	-50 %

Sources: The IGLLB index of unit damages is from data supplied by the U.S. Army Corps of Engineers, North Central Division, Chicago District 1975.

The index of income is an approximation of 1972 OBERS indices of total personal income and of per capita income in Wisconsin BEA's and SMSA's (Wisconsin Department of Administration 1974).

Projected damages—allocation of future shoreline uses. Changes in the allocation of coastal land uses does not substantially alter the index of total unit damages. Reach 7003 (Milwaukee to Manitowoc) was used to test the sensitivity of the index of total unit damages to changes in projected miles of shore use. The IGLLB projects an increase of 17 miles in parks and beaches between 1966 and 2020, but only a 3.2 mile increase of residential property. However, Department of Natural Resources personnel studying public access on Wisconsin's shoreline state that such a large increase in parks and beaches on Reach 7003 appears unlikely.* Therefore, the University study group substituted a projected increase of only five miles of parks and beaches and 15.2 miles of residential property for the IGLLB projections. These substitutions produced only a small change in the index of total unit damages from 1,098 to 1,201.

Projected damages—effect of more strict zoning. Institution of more stringent zoning in areas of new construction does not significantly change the projected damages. Although the IGLLB recommends adoption of strict coastal land use controls, the analysis of shore damages assumes that existing development patterns will continue. Reaches 9002 and 7003 were used as test cases where zoning is presumed to provide 75% protection to residential property developed between 1966 and 2020. On Reach 9002 zoning reduced the index of total unit damages from 475 to 425 (12%). On Reach 7003 the index changed from 1,098 to 1,085 (1.2%). The resulting reduction in average annual shore damage is insignificant. Therefore, the IGLLB projected damages are not sensitive to changes in land use controls. Because this test does not account for protection provided to new structures in presently developed areas, the University analysis may underestimate the effect of zoning.

Protection and property value. The IGLLB criterion for determining which property will be protected is not directly related to the decisions that a private property owner faces. The IGLLB states that if the "present-day market value of property" equals or exceeds the estimated cost of protection, then the property will be protected (IGLLB 1973, Appendix C, p. C-20). This statement is somewhat misleading. Discussion with members of the IGLLB Shore Property subcommittee revealed that the actual criterion was that, if the expected damages equal or exceed the cost of protection, then the property will be protected (Carlson 1975). The costs per mile of appropriate protection (determined by district engineer's judgment as either groins, sheet steel bulkheads, cellular steel pile seawall or stone seawall) were compared to the expected damages per mile. This protection assumption was based on Corps policy rather than on observation of actual behavior of shore property owners. Often the property owner is constrained by lack of adequate capital or lengthy permit procedures which prevent protection. (See Appendix B for comments on expected value of damages.)

Permanence of protection. The IGLLB assumed that protection is permanent and totally effective. In fact, installation of protective structures may accelerate erosion nearby. In addition, while the analysis did consider differences in construction heights of structures under given regulation plans, attention was not given to differences in the useful life of protective structures under various regulation plans. Some determination of useful life and effectiveness of protective structures would have been helpful.

* Scott Mernitz. Wisconsin Department of Natural Resources. Personal Communication, July 24, 1975.

D. EVALUATION OF REGULATION PLANS THROUGH STAGE-DAMAGE CURVES

1. The 1965 Corps of Engineers Study on Lake Erie

Integration of estimates on ultimate water levels and damages into stage-damage curves permitted comparison of regulation plans. The IGLLB analysis initially followed the method employed in a study of the 1951-1952 damages and levels experienced on Lake Erie (U.S. Army Corps of Engineers 1965). Using the 1952 damage survey, the Corps' 1965 study estimated the damages at three ultimate water levels based on the following conditions:

- An ultimate water level equal to the mean level of Lake Erie (1900-1967)
- The ultimate water level (May 1951-April 1952) and the associated adjusted damage for one month per mile of unprotected shore
- An estimate of the adjusted damages from ultimate water levels one foot higher than those experienced in 1951-1952. These estimates were obtained in 1965 by Corps personnel who had participated in the 1952 survey.

As in the later IGLLB study, the 1965 study eliminated from the analysis those properties damaged in 1952 which had since been protected; in addition, the analysis subtracted out damages occurring to properties whose 1964 value exceeded the cost of protection. From approximately \$12,000,000 of damages found in 1952 (between the Detroit River and Erie), the 1965 adjustment reduced this figure to \$2,430,000 (U.S. Army Corps of Engineers 1965, pp. C-37-38). The estimate of updated damages at one foot higher ultimate water levels was \$4,050,000. The second adjustment used the Engineering News Record construction cost index to update the 1952 adjusted damages to July 1964 price levels. Multiplying the damages by 1.72 yielded estimates of \$4,180,000 and \$6,966,000 for the two damage figures, respectively.

Therefore, the Corps had three distinct sets of ultimate water levels for Lake Erie—where no damages occur, an ultimate water level from the 1951-1952 period, and a level one foot higher than that experienced in 1951-1952. Associated with the latter two levels are figures on the total damages per month per mile of shoreline experiencing damages—158.1 miles on Lake Erie. The following points define the curve:

Ultimate water level feet IGLD (1955)	Damages, July 1964 Price Level (1952 Developments)	
	For 12 months and 158.1 miles of shore	For 1 month per mile of shore
570.60	0	0
574.33	\$ 4,180,000	\$ 2,200
575.33	\$ 6,966,000	\$ 3,670

Having defined the curve with the above points, the Corps used the 36 ultimate water levels from 1951-1952 (12 from each of the three reaches) to derive an equation which reasonably reproduced the total adjusted damages from the 1952 survey. This equation is

$$D = 121.9(S-570.60)^{2.17}$$

where D equals the average damage per month per mile of shore property and S is the monthly ultimate water level on Lake Erie. This equation nearly reproduces the initial damage per month per mile points given above. In 1966-1967 the IGLLB accepted the general form of this equation (not the equation itself) as being representative of the water level-damage relationship (IGLLB 1973, Appendix C, pp. C-36-37).

Exclusion of property economically feasible to protect. The Corps' consideration of only those properties which were not economically feasible to protect and which would sustain damages in the future reduced by 80% (from about \$12,000,000 to \$2,430,000) the amount of 1951-1952 damages recognized in the 1965 study. The \$2,430,000 used for the 1965 study represents 100% of damages to public property and to agricultural property and only 10% of damages to private property other than agriculture. Therefore, the stage-damage curve developed by the Corps for Lake Erie does not simply relate the reported damages of the 1952 survey to the ultimate water levels which occurred then.

Stage-damage curve—curvilinear function. Both the Corps' 1965 study and the IGLLB assume that a curvilinear function defines the relationship between damages and water level. However, no studies have been made to confirm this definition. The Corps' study suggests that, because substantially more damage occurs at higher water levels, a curvilinear function is appropriate (U.S. Army Corps of Engineers 1965, p. C-23). Such a relationship might also be defined by a step function. Because small increments of the curve are used when ultimate water levels of various plans are compared, substantiation of the function is necessary.

Zero damage level. The Corps' 1965 study and the IGLLB both incorrectly assume that all shore damages are caused by wave attack. Bluff recession may also be caused by frost action, groundwater seepage, and surface water runoff. Because damages from these forces are not eliminated from the IGLLB analysis, the benefits and losses of regulating water levels may be somewhat overstated.

2. The IGLLB Study—Calculating the Effects of Lake Level Regulation for 1972-2022

Beginning in 1966 the Shore Property subcommittee of the IGLLB extended the same analysis developed by the Corps for Lake Erie to each of the 36 United States reaches. Since the IGLLB accepted for its study the general shape of the Corps' stage-damage curve, it did not estimate the damages at one foot higher ultimate water levels. Damage curves were developed for each reach recognizing that some damaged properties included in the 1952 survey subsequently had been protected. Essentially, the IGLLB adjusted the 1952 damage data using the same criteria as in the 1965 study with two exceptions. First, the damages reported in 1952 were updated to September 1966 price levels. Secondly, the study calculated the average damages to each type of property and applied this figure to the changes in land use which had occurred between 1952-1966 (IGLLB 1973, Appendix C, p. C-37). Thus, if from 1952 to 1966 the number of miles devoted to residential use increased, the total damage figure would reflect this change.

The IGLLB next constructed a stage-damage curve with the 1951-1952 ultimate water levels and the total damages per month per mile—adjusted to 1966 prices and conditions. When updating the damages on the Sandusky-Erie reach to 1966 conditions, the IGLLB concluded that a log-log curve approximated the original 1965 stage-damage curve. Use of log-log curves simplified the task of creating a stage-damage curve which reproduced the synthesized 1966 damages. Thus, for each reach the IGLLB developed a straight line on log-log paper which related 1951-1952 ultimate water levels to monthly damages per mile of unprotected shore (IGLLB 1973, Appendix C, p. C-37).

The final step in predicting damages with each stage-damage curve was the writing of a computer program which weighted the frequency of occurrence of ultimate water levels under Basis-of-Comparison conditions and a regulation plan. To achieve this the IGLLB tabulated the total damages associated with one-half foot ultimate water level intervals. With a computer program the IGLLB assigned a damage figure to every monthly ultimate water level computed for a specific reach. Since the number of ultimate water levels computed in a reach depended upon the availability of wind data, some reaches had more data points than others. For example, Reach 9002 on Lake Superior had fourteen years of record, and the adjoining Reach 9003 had fifty-nine. As Table 5 shows, the damages associated with each water level were multiplied by a frequency interval such as 0.071. This frequency weighting varied according to the number of years of record. The sum of the weighted damages (Column 4, Table 5), when multiplied by the number of shoreline miles, yielded a total monthly damage figure. Table 6 shows a sample calculation under SO-901 as compared with Basis-of-Comparison. Summaries of monthly weighted damage figures are presented in the table.

TABLE 5 COMPARISON OF SHORELINE DAMAGE. ULTIMATE WATER LEVELS
REACH 9002—NOVEMBER

BASIS-OF-COMPARISON						PLAN SO-901		
	Exceeding Frequency Mean (1)		Adjusted Natural UWL (2)	Damages /MO/MI (3)	Damages x Freq (4)	Regulated UWL (5)	Damages /MO/MI (6)	Damages x Freq (7)
1	0.0	7.1	613.20	4338	308	613.66	4829	343
2	7.1	14.2	611.13	2386	169	612.35	3479	247
3	14.2	21.4	608.52	790	57	609.31	1186	85
4	21.4	28.5	608.51	785	56	608.63	846	60
5	28.5	35.7	608.18	641	46	607.55	411	30
6	35.7	42.8	608.14	624	44	607.08	288	20
7	42.8	50.0	607.06	283	20	606.73	218	16
8	50.0	57.1	606.06	137	10	605.90	126	9
9	57.1	64.2	606.05	136	10	605.86	124	9
10	64.2	71.4	605.76	118	8	605.81	121	9
11	71.4	78.5	605.70	115	8	604.70	69	5
12	78.5	85.7	601.31	3	0	601.38	4	0
13	85.7	92.8	600.81	1	0	600.63	0	0
14	92.8	100.0	600.70	0	0	600.22	0	0
Sum					736.			833.
Times 202.5 Miles of S/L					149040.			168683.

Source: IGLLB 1968.

TABLE 6 COMPARISON OF SHORELINE DAMAGE. ULTIMATE WATER LEVELS
REACH 9002—SUMMARY

BASIS-OF-COMPARISON			PLAN SO-901		Difference
MON	Total Damage Per Mile	Total Damage For Reach	Total Damage Per Mile	Total Damage For Reach	
Jan	303.00	61358.00	264.00	53460.50	7897.50
Feb	361.00	73103.00	298.00	60345.50	12757.50
Mar	146.00	29565.50	140.00	28350.50	1215.00
Apr	359.00	72698.00	426.00	86265.50	-13567.50
May	307.00	62168.00	396.00	80190.50	-18022.50
Jun	176.00	35640.50	159.00	32198.00	3442.50
Jul	193.00	39083.00	185.00	37463.00	1620.00
Aug	451.00	91328.00	413.00	83633.00	7695.00
Sep	565.00	114413.00	537.00	108743.00	5670.00
Oct	217.00	43943.00	225.00	45563.00	-1620.00
Nov	736.00	149040.50	833.00	168683.00	-19642.50
Dec	734.00	148635.50	679.00	137498.00	11137.50
Sum	4548.00	920976.00	4555.00	922393.50	-1417.50

Source: IGLLB 1968.

Intead of redrawing a curve on every reach for 1980, 2000, and 2020, the IGLLB used the "shortcut" procedure described in section C.3. The indices of total unit damages per mile (Row E, Column 1, Table 2) were applied to the dollar damage difference between regulation plans as shown in Table 6. Using a 7% discount rate the IGLLB calculated the average annual effect of a regulation plan over a project period with the damage estimates at 1966, 1980, 2000, and 2020 as interval points (IGLLB 1973, Main Report, p. 76).

Distribution of monthly ultimate water levels. Analysis of the monthly distribution of ultimate water levels on Reach 9003 (Sand Bay, WI to Presque Isle River, MI) indicates that most ultimate water levels are relatively low and the frequency of higher levels decreases as ultimate water levels increase. The distribution of ultimate water levels for any month appears to approximate a Log Normal or a Pearson Type III distribution (Appendix B, Figure 9). The IGLLB method of assigning a discrete frequency count to each ultimate water level to define the distribution is justifiable, given the lack of statistical verification for any assumed distribution.

Period of record—wind data. In most cases, approximately 60 years of wind data are used to calculate ultimate water levels and, thus, average damages per month per mile. Because only 14 years of wind data are available at Duluth, some differences between damages on Lake Superior reaches may occur because of the large difference in the amount of wind data. However, the IGLLB was probably correct in using all available information so long as the differences in records are remembered.

Inclusion of winter months. Calculation of ultimate water levels during winter months when ice protects the shore is improper. The IGLLB suggests that elimination of ice covered months is an "unnecessary refinement" in methodology if the same methods are used in comparing plans (IGLLB 1973, Appendix C, p. C-35). However, a significant percentage of damages is indicated for the months of January through March when no damages would be expected (17% on Reach 9002 and 24% on Reach 9003). The result is that damages which occur in the spring and the fall are understated while the effects of winter regulation are overstated. Therefore, stage-damage curves should be recalculated using only ice free months.

Addressing the problems of uncertainty. The University analysis of the IGLLB's method for estimating the impacts to shore property of further regulation emphasizes the uncertainty in predicting effects of small water level changes. There is little justification for the IGLLB's use of 5 or 6 significant figures to estimate damages or benefits (Table 6). Although the IGLLB contends that their numerical results reveal only qualitative differences between plans, failure to accept uncertainty in one's methods, in this case evidenced by use of more than one, two, or even three significant figures, serves only to provide the unwitting reader or decisionmaker with a false sense of certainty in the IGLLB's results. Greater emphasis upon the range of possible outcomes could help temper overly confident interpretations of the IGLLB's results.

E. COMPARISON OF THE UNITED STATES AND CANADIAN METHODS OF ESTIMATING EROSION AND FLOODING LOSSES

The method of relating lake levels to shore damages employed by the Canadian section of the Shore Property subcommittee differs considerably from the United States procedure. These differences in method could produce widely varying estimates of annual average damages. When the IGLLB compared methods on two reaches of the United States shore along Lakes Ontario and Erie, agreement of results varied according to the reach or operating plan tested (Table 7). Comparison of the methods on the Lake Ontario reach using various SEO and SO plans showed that the damage estimates may vary by as much as 173%; even under the Basis-of-Comparison levels the estimates differ by 33%. On the Lake Erie test reach the estimates vary from a negligible amount for Plan SO-802, which is very similar to SO-901, to a difference of nearly \$200,000 for Plan SO-(OPT). It should be noted that for all but one plan on Lake Ontario the United States method showed more benefits than the Canadian procedure, while on the Lake Erie reach in four of the six test cases the Canadian method showed greater benefits. Therefore, substantial differences in damage estimates could occur depending upon which method is used. More importantly, however, neither method is inherently more accurate than the other.

TABLE 7 RESULTS OF COMPARISON TESTS ON EROSION AND INUNDATION LOSSES
USING THE UNITED STATES AND CANADIAN METHODS

Lake Ontario test reach, Oak Orchard Creek to Rochester Harbor:

Test level regime*	Method	Average annual damages	Percentage difference between damage estimates
Basis-of-Comparison	U.S.	\$ 168,000	33 %
	Canada	224,000	
SEO (501)	U.S.	172,000	32 %
	Canada	227,000	
SEO (Optimal)	U.S.	14,600	173 %
	Canada	39,900	
SO (701)	U.S.	21,000	148 %
	Canada	52,000	
SO (Optimal)	U.S.	32,900	27 %
	Canada	24,000	

Lake Erie test reach, Cleveland to Fairport Harbor:

Basis-of-Comparison	U.S.	\$ 307,000	9 %
	Canada	278,000	
SEO (501)	U.S.	217,000	28 %
	Canada	277,000	
SEO (Optimal)	U.S.	285,000	40 %
	Canada	171,000	
SO (802)	U.S.	296,000	6 %
	Canada	279,000	
SO (Optimal)	U.S.	68,800	294 %
	Canada	268,000	
SO (701)	U.S.	294,000	4 %
	Canada	281,000	

Source: IGLLB 1973, Appendix C, pp. C-113-144. Tables C-20 and C-21.

* Optimal plans assume no preexisting structural or institutional constraints upon maximizing total benefits.

These disparities in damage estimates result from the important differences in the two methods. Although it is not possible to identify conclusively why the methods yield results which can vary, the important differences between the two methods are listed below:

1. *Relating damages to wave energy.* While the United States section calculated ultimate water levels and modified the 1951-1952 damage figures to develop a stage-damage curve, the Canadians related estimated erosion damages and instances of recorded storm damage to a wave energy index. The Canadian method assumed that erosion or storm damages are "directly proportional to the wave energy flux reaching the shore cliff face under a level system . . ." (IGLLB 1973, Appendix C, p. C-55). Lacking almost any recorded erosion damages, the Canadians divided the shores of Lake Huron, Erie, and Ontario into reaches and then into subreaches to better categorize shore profiles, wave climates, recession rates, and property values. With this data, the Canadians constructed a mathematical model which expressed average damages for each month as a function of meteorological and hydrological factors, damages at a mean annual water level, and the variance of the monthly mean levels for each month (IGLLB 1973, Appendix C, pp. C-63-67).
2. *Source of the Canadian estimates of damages.* Average annual losses due to erosion were measured as one-fiftieth of the property value lost at a given recession rate between 1972-2022 (IGLLB 1973, Appendix C, pp. C-44, 59). In addition to this estimate of erosion damages, the Canadians calculated flooding losses from surveys of sample reaches following major storms (IGLLB 1973, Appendix C, p. C-59). Unlike the United States procedure, which had one total damage value from the 1951-1952 survey, the Canadians separately calculated the indices of damaging capacity for erosion and storm damages. Addition of these indices yielded a composite stage-damage relationship on each subreach (IGLLB 1973, Appendix C, pp. C-59-60).
3. *Estimating damages over ten months rather than twelve.* The Canadians assumed that during January and February ice cover would minimize erosion and flooding damages due to lake levels, and therefore they distributed the average annual losses over ten months rather than twelve as in the United States method. This difference may have an important effect on the results because the projected total damages per mile during January or February for the Wisconsin shore of Lake Superior under the United States method can exceed the projected damages for other months. Unfortunately, the IGLLB did not compare the methods on Lake Superior; even if a comparison had been made, it would be difficult to isolate which differences in damage estimates were caused by using ten months rather than twelve.
4. *Relating the variance of mean monthly levels to damages.* The Canadian method explicitly accounted for the effect of alteration in the variance of mean monthly levels (i.e., all the June levels) by modifying the Basis-of-Comparison standard deviations. For example, a change of -0.2 in the standard deviation of mean monthly levels reduces the average monthly damages by approximately 7% (IGLLB 1973, Appendix C, pp. 60-62). With the Canadian method approximately 80% of the effect of Plan SO-901 is attributed to modifying the variance of monthly means (IGLLB 1973, Appendix C, pp. 60-75). The United States, however,

calculated the ultimate water levels for each month where data were available and then assigned the same frequency of occurrence to each and its associated amount of damages per month per mile ultimate water level (see section D.2). Since the United States method assumes that a regulation plan affects damages according to the amount it reduces the ultimate water level in any given month, the two methods may be expressing the same principle, but in different ways.

Unfortunately, it is not known how these differences (and possibly others) offset each other. Considering the disparities between the methods, even the relatively good agreement in damage estimates on the Lake Erie test reach is surprising.

Although the two methods are very different, the estimates of damages show greater agreement when the losses are potentially great (Table 7). Since both methods agree upon the general trend of losses under different operating plans, should the methods be compared on other lakes? Although both the United States and Canadian sections of the IGLLB emphasized that their results are relative measures of the damages which may occur under a regulation plan, the above considerations indicate the high degree of uncertainty inherent in the methods. Further comparison of the methods for reaches on Lakes Superior, Michigan, and Huron may validate the IGLLB's qualitative conclusions about the SO and SEO plans.

F. COMPARISON OF SELECTED REGULATION PLANS

1. Uncertainty and Bias in Shore Damage Calculation

The range of possible shore benefits under various regulation plans is an important consideration. For example, knowing the range of possible losses to U.S. shore interests on Lake Superior may be more useful than simply noting the \$124,000 annual average loss indicated in Table 8. In addition, because there are a number of factors which can affect the stated annual average benefits of a regulation plan, one should not only consider the stated dollar benefit but also develop an understanding of how the plan operates. Thus, one can weigh economic calculations against a basic understanding of how the levels and Great Lakes interests are affected by various plans.

Two major areas of uncertainty in the shore property analysis are (1) future net basin supplies to the Great Lakes, and (2) population and income projections used to project property value, land use, and protection. In order to obtain an indication of the range of results of Plan SO-901 under various possible supplies, the IGLLB tested the plan under a number of simulated supply sequences.* Generalized loss curves were used to identify the economic consequences of each sequence to the Great Lakes interests. The generalized loss curves are simplifications of the functions used to compute the economic impact to each of the six interests, i.e., power, navigation, and shore interests on each of Lakes Superior, Michigan, Huron, Erie, and Ontario. Each generalized loss curve relates the monthly mean elevation of a lake to a particular dollar benefit or loss. Generalized loss curves are only "crude representations" of the detailed functions, but they served adequately to provide a preliminary understanding of various plans and supply sequences (IGLLB 1973, Main Report, pp. 70-72).

* B. G. DeCook, Chairman, IGLLB Regulation Subcommittee, Personal Communication, August 4, 1975.

TABLE 8 AVERAGE ANNUAL BENEFITS TO SHORE PROPERTY—(\$1,000)

Lake	SO-901		SEO-17P*		SO-901 Mod 7**	SO-901 Mod 8**
	Erosion & Inundation	Total	Erosion & Inundation	Total	Total	Total
Superior	-115	-124	299	299	1,200	1,500
Michigan	156	244	1,330	2,503	1,200	1,300
Huron	101	177	397	631	---	---
St. Clair	73	73	244	254	---	---
Eric	386	465	4,398	4,796	200	200
Ontario	- 38	- 32	1,402	1,540	100	100
GREAT LAKES	563	803	8,070	10,023	2,700	3,100

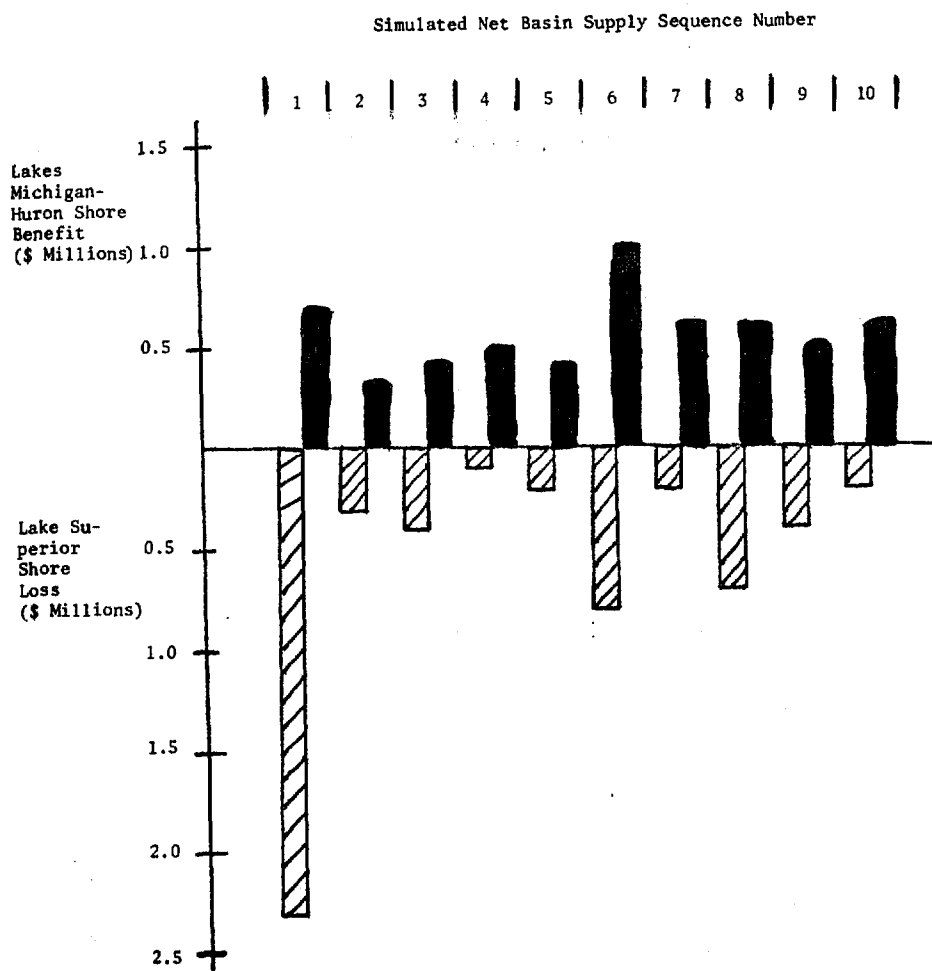
Sources: IGLLB 1973, Main Report, pp. 139, 141.
U.S. Army Corps of Engineers 1974, p. 38.

* Includes U.S. shore only.

** Calculated by generalized loss curves only rather than by detailed method.

Ten of the simulated supply sequences used for testing SO-901 are summarized in the IGLLB Main Report 1973 (p. 136). A comparison of the range of economic benefits and losses with those computed under base period supplies is enlightening. In all cases there is an overall economic gain of from \$400,000 to \$2,700,000 compared to a \$2,370,000 gain under base period supplies. In four of the cases, however, the benefits to Lakes Michigan and Huron shore interests do not exceed the losses to Lake Superior shore interests. Under base period supplies (Table 8) a \$421,000 benefit to Lakes Michigan and Huron shore interests compared to a \$124,000 loss to Lake Superior shore interests. The range of possible losses to Lake Superior shore interests extends from \$100,000 to \$2,300,000 while on Lakes Michigan and Huron, a narrower range of possible shore benefits extends from \$300,000 to \$1,000,000 (Figure 6). Thus, a comparison of the simulated supply sequences with the base period supplies indicates that the stated benefits of Plan SO-901 are optimistic in relation to the range of possible results, and that Lake Superior shore property losses may exceed Lake Michigan shore property gains.

FIGURE 6 COMPARISON OF LAKES MICHIGAN-HURON SHORE BENEFITS WITH LAKE SUPERIOR SHORE LOSSES USING TEN SIMULATED NET BASIN SUPPLY SEQUENCES AND IGLLB GENERALIZED LOSS CURVES



Source: IGLLB 1973, Main Report, p. 136.

Another important factor affecting the shore property analysis is the uncertainty associated with the population and income projections used to calculate future property values and protection. In examining the possible range of these inputs for erosion and inundation, the IGLLB concluded that average annual benefits may range from as much as 45% greater to 32% less than the stated amount (IGLLB 1973, Appendix C, pp. C-101-102). The uncertainty is compounded with that associated with the range of possible supplies. Since marine structures, water intakes and sewer outfalls, and recreation beaches are also included under the shore property category, the uncertainty associated with the erosion and inundation method cannot be applied directly to the figures provided by the generalized loss curves for shore property. However, erosion and inundation is the most substantial portion of these damages (under SO-901 at base supplies it is \$115,000 of \$124,000 on Lake Superior and \$156,000 of \$244,000 on Lake Michigan) and therefore, the uncertainty associated with erosion and inundation contributes considerably to the overall uncertainty associated with shore property damage estimates.

In addition to uncertainty, any bias in the method can increase the range of possible benefits or losses occurring from regulation. For example, the IGLLB definition of breaking depth which is used to calculate ultimate water level (see section II.A) understates breaking depth when regulation lowers the mean water level and overstates breaking depth when regulation raises water levels. Bias occurs in comparing Lake Superior and Lake Michigan. Because the dollar damages are much greater on Lake Michigan than they are on Lake Superior, overestimation of the benefits of lowering Lake Michigan levels is much larger than the overestimation of Lake Superior losses. Therefore, the method is biased in favor of lowering Lake Michigan levels.

2. Plans SO-901, SEO-17P, SO-901 Mod 7 and SO-901 Mod 8

At present, four regulation plans have received major consideration for managing Great Lakes levels. All four utilize the concept of regulating the flow from Lake Superior according to the relative difference of Lake Superior and Lakes Michigan-Huron from their monthly means. Thus, when Lake Superior levels are relatively higher than Lakes Michigan-Huron levels, flow is increased; when Lakes Michigan-Huron levels are relatively higher, flow is decreased, and when both are at the same relative level, the discharge follows the previous rule. The IGLLB performed detailed analyses of the economic impacts to shore interests affected by Plans SO-901 and SEO-17P. Recently, the state of Michigan recommended further evaluation of Plans SO-901 Mod 7 and SO-901 Mod 8 which have only been tested with generalized loss curves.* In this section, the effects of the four plans on shore property interests, specifically on Lakes Superior and Michigan, will be discussed.

Plan SO-901. Since February 1, 1973, the Lake Superior Board of Control has used this plan as a guide for regulating the flow from Lake Superior (IGLLB 1973, Main Report, p. 236). The IGLLB estimates that under base period supplies an average annual loss of \$124,000 occurs to shore property interests on Lake Superior, while Lake Michigan shore interests gain \$244,000 (Table 8). However, when the uncertainty associated with possible supplies and with the method is considered, there is a fair chance that the loss to Lake Superior shore interests will exceed the benefits to that interest on Lake Michigan. In 4 of the 10 simulated supply sequences published in the IGLLB Main Report (p. 136), losses to shore interests on Lake Superior exceed the shore benefits to Lake Michigan. In all of these simulated sequences, however, an overall benefit to the Great Lakes of \$400,000 to \$2,700,000 occurs.

Plan SEO-17P. This plan operates according to the same rule for regulating Lake Superior outflow as Plan SO-901, and in addition, includes construction of a diversion across Squaw Island which will allow increased effective flow of up to 17,500 cfs from Lake Erie (U.S. Corps of Engineers 1974, p. 9). Total benefits to shore property are \$10,023,000 including a \$299,000 benefit to Lake Superior and a \$2,503,000 benefit to Lake Michigan (Table 8). Practically all of Lake Superior benefits can be attributed to a reduction of erosion and inundation. Recreation beaches account for approximately one-half (\$1,215,000) of Lake Michigan benefits, and erosion and inundation accounts for the other half (\$1,330,000). Relatively minor amounts of losses and benefits occur to water intakes and sewer outfalls or to marine structures.

* Patrick J. Lucey, Governor of Wisconsin. 1975. Personal Communication. Correspondence to Governor William G. Milliken, Michigan. June 19.

This plan and the benefits attributed to it deserve closer scrutiny. The mean monthly levels are only a few hundredths of a foot different from SEO-42P levels on Superior and Michigan-Huron (U.S. Army Corps of Engineers 1974, pp. 10-13). There are only slightly more occurrences of low levels and several fewer high levels. Upon comparison of Plan SEO-42P (very similar to SEO-17P) with Plan SO-901 for the period of 1900-1973, Michigan-Huron levels under SEO-42P do not differ from SO-901 by more than 14 hundredths of a foot and on Lake Superior by more than 12 hundredths of a foot (University of Wisconsin 1975). Because SEO-42P is consistently only a few hundredths of a foot lower than SO-901, the benefits indicated for SEO-17P appear strangely to be considerably greater than those under SO-901. Uncertainty associated with a range of possible supplies should also be considered. When this aspect is taken into account the range of benefits and losses may be substantial (see section F.1) for discussion of simulated supplies) so that the occurrence of a loss to Lake Superior shore interests of several hundred thousand dollars may be quite possible.

Plans SO-901 Mod 7 and SO-901 Mod 8. In discussing various structural alternatives to Plan SO-901, the IGLLB briefly mentions these two plans (IGLLB 1973, Main Report, pp. 137-139). These plans utilize Lake Superior's natural range plus a one-foot lowering of the minimum stage. Shore property benefits of these plans were computed using the generalized loss curves. Shore benefits under Mod 7 are indicated as \$1,200,000 on Lake Superior and an equal amount on Lakes Michigan-Huron (Table 8). Under Mod 8 Lake Superior shore benefits are \$1,500,000, and they are \$1,300,000 on Lakes Michigan-Huron. Both Mod plans tend to reduce the variance of levels on Lakes Michigan-Huron although the means are not changed from Plan SO-901. On Lake Superior, however, levels are lowered substantially from those under Plan SO-901. These plans appear to provide substantial benefits to shore property interests. However, since the IGLLB made only a very superficial analysis of these plans, a more careful analysis of economic and environmental impacts under base period and simulated supply sequences is desirable.

III. RECREATION

INTRODUCTION

In evaluating the effect upon recreation of changing the regulation of Great Lakes water levels, the International Great Lakes Levels Board (IGLLB) addressed (1) recreational beaches, and (2) recreational structures and boating. The IGLLB maintained that the impact of regulation on marinas and boat use would be minimal, while increased beach acreage would provide a substantial portion of the economic benefits from regulation plans SO-901 and particularly SEO-17P (Table 9). Although the IGLLB's method of evaluating the effects of lake level fluctuation on recreation appears to be sound and to offer a useful comparison between regulation plans, several assumptions concerning recreational beaches may tend to overstate the benefits of implementing SO-901 and SEO-17P. These premises include projections of existing and future beach use and nearshore water quality. More importantly, however, is to realize that even a small change in lake levels (0.01 feet) will have a significant economic impact upon recreational beach use, according to the IGLLB methodology (IGLLB 1973, Appendix D, p. D-169).

TABLE 9 PROJECTED CHANGE IN AVERAGE ANNUAL BENEFITS TO RECREATIONAL BEACHES FROM PLANS SEO-17P AND SO-901 AS COMPARED WITH THE BASIS-OF-COMPARISON LEVELS (\$1,000)

<u>Lake</u>	<u>Country</u>	<u>Regulation Plans</u>	
		<u>SO-901</u>	<u>SEO-17P</u>
Superior	U.S.	- 5	+ 4
	Canada	0	
Michigan	U.S.	+ 82	+1,215
	Canada	+ 17	+ 239
Huron	U.S.	+ 56	
	Canada		
St. Clair	U.S.	0	+ 10
	Canada	0	
Erie	U.S.	+ 18	+ 462
	Canada	+ 56	
Ontario	U.S.	+ 4	+ 146
	Canada	0	
Great Lakes	U.S.	+116	+2,076
	Canada	+112	
TOTAL		+228	2,076

Recreation Beaches as Percentage
of Total Benefits from the Plan*

9.6% 21%*

Source: IGLLB 1973, Main Report, p. 141.
U.S. Army Corps of Engineers 1974.

*Benefits for SO-901 were calculated using the detailed economic analyses, while benefits for SEO-17P were obtained from the detailed analysis of shore property and general analyses for navigation and power.

A. RECREATIONAL BEACHES

Members of the United States subcommittee from the Bureau of Outdoor Recreation (BOR) and the Army Corps of Engineers evaluated the economic impacts of lake level regulation on recreational beaches. They measured the difference in the user day value of beach area exposed under a regulation plan and the user day value calculated using the Basis-of-Comparison (BOC) levels. Average annual benefits which result from lowering summer mean monthly water levels under several regulation plans are substantial. Using 1900-1967 net basin supplies, the IGLLB estimates that Plan SO-901 could generate average annual benefits of \$228,000 for beaches on the Great Lakes. This figure is 9.6% of the estimated total average annual benefits generated by SO-901 (Table 9).

Estimated benefits generated by Plan SEO-17P for recreational beaches are \$2,076,000 annually for all the lakes; this figure represents approximately 21% of the total average annual benefits accruing to the United States from the plan. Although these projected benefits occur primarily on Lakes Michigan and Erie, the average annual benefits, due to increased beach acreage in Wisconsin will be small because Wisconsin, Michigan, Indiana, and Illinois share the benefit accruing to Lake Michigan beaches. The following sections of this working paper consider the assumptions and methods used by the IGLLB to calculate the impact of new regulation plans. Some of the factors chosen by the IGLLB are subjective, and the results vary considerably if the assumptions are changed.

1. Assumptions of the IGLLB Analysis of Beaches

The IGLLB based their recreational beach evaluation on the following premises concerning demand:

- "Demand for beaches in urbanized areas of the Great Lakes far exceeds existing supply, except in low density population areas" (IGLLB 1973, Appendix D, p. D-134)
- Future increases in population, mobility, affluence, and leisure time will create an increased demand for beaches. "While population is projected to increase about 80% between 1972 and 2022, swimming beach acreage requirements for the Great Lakes basin area during the same time period are expected to increase about 300%" (IGLLB 1973, Appendix D, p. D-134). It is important to note that this projected increase applies to the entire basin—not only Great Lakes beaches. Table 10 shows the projected increases of beach acreage along the Great Lakes.

TABLE 10 PROJECTED INCREASE OF BEACH ACREAGE

<u>Lake</u>	<u>1972 Supply</u>	<u>50-year increase 1972-2022</u>	<u>Projected 2022 supply</u>	<u>% increase (rounded to nearest 10%)</u>
Superior	290	145	435	50%
Michigan	1,120	732	1,852	70%
Huron	110	100	210	90%
Erie	700	140	840	20%
Ontario	130	93	223	70%

Source: IGLLB 1973, Appendix D, pp. D-141-142.

- "The addition or subtraction of beach area provides a basis for measuring the change in recreational value due to regulation" (IGLLB 1973, Appendix D, p. D-124).
- "Each person using a beach requires a certain area. The size of the area depends upon the intensity of use related to beach area available. A monetary value for a beach user day can be assigned. Water quality has an effect on the user day value. The range in user capability value associated with regulation provides a basis for judging the merits of regulation plans" (IGLLB 1973, Appendix D, pp. D-124-125).
- Beach use on a weekday will amount to one-third of a beach's theoretical daily attendance potential which is 100% on weekends and holidays. The beach use season extends from June 1 through September 30. U.S. use is distributed as follows: June 15%, July 40%, August 40%, and September 5%. Adverse weather results in a reduction of 20% in total attendance potential throughout the recreation season (IGLLB 1973, Appendix D, p. D-125).
- Projection of values for the project period includes:
 - "That all 1972 moderate intensity beaches will become high intensity use beaches by 2022;
 - That all 1972 low-intensity beaches will become moderate intensity use beaches by 2022;
 - That all "E" quality use beaches (closed due to pollution) will become high intensity use "B" quality beaches by 2022" (IGLLB 1973, Appendix D, p. D-141).

There are at least two important aspects to these assumptions. The IGLLB assumed that any increase in beach acreage due to a regulation plan will yield a benefit because demand for beach recreation exceeds the supply of beaches. Although the IGLLB projection of a 300% increase in beach acreage requirements (1972-2022) for all beaches in the Great Lakes Basin is a reasonable assumption (Somersan 1975), the popularity of swimming in the Great Lakes may actually be leveling off or declining. Huddleston et al. (1975) projected that the increasing availability of indoor swimming facilities, competition from other forms of recreation—particularly hiking, tennis, and bicycling, and enhanced awareness of poor water quality could cause a decline in the swimming participation rate of Midwestern families. As Holman and Bennett (1973) have also noted, assuming that the use of swimming facilities will increase if more beaches exist ". . . is naive and ignores the fact that the recreational experience often involves a number of activities when other facilities are available." Numerous authors have found that projecting recreation demand requires consideration of many variables besides beach area (Clawson and Knetsch 1966; Seneca and Cicchetti 1969; Holman and Bennett 1973). The contention presented in this working paper is not that benefits will fail to accrue from lower water levels, but rather that any projections about the economic impact of water level changes on recreational beach users are subject to considerable uncertainty.

For example, the IGLLB method of calculating benefits from increased beach acreage is very sensitive to the following assumptions: (1) all moderately used beaches will become high intensity use beaches by 2022, and (2) that low intensity use areas will be moderately used by 2022. If, as the IGLLB assumed, moderately used beaches have a user density of 500 square feet per person, projecting that this beach will be intensively used (100 square feet per person) increases the economic effect of regulation on those beaches by a factor of five.

A recent Wisconsin Department of Natural Resources (DNR) research report also casts doubt upon the IGLLB's premise that public demand for coastal beaches exceeds their supply (Cohee 1970). Using the IGLLB method and survey data (1967), the maximum density of beach use at Terry Andrae State Park (Sheboygan County) is approximately 871 people per beach acre.* Cohee, however, recorded the following maximum densities for 17 inland privately owned, commercially operated beaches in Wisconsin:

- Statewide—1,062 people per beach acre
- Southeast Wisconsin—1,638 people per beach acre.

* This figure was calculated in the following manner using the IGLLB method and Bureau of Outdoor Recreation field data (1967) compiled for the IGLLB study.

- (1) Daily attendance potential = area of beach at the recorded water level (578.5 feet) divided by a density figure obtained from the beach survey multiplied by the turnover rate.

$$8,173 \text{ people} = 408,672 \text{ ft.}^2 (9.38 \text{ Ac.}) \div 100 \text{ ft.}^2 \text{ per person} * 2 \text{ people per day}$$

- (2) Density of use = daily attendance potential divided by area.

$$871 \text{ people per acre} = 8,173 \text{ people} \div 9.38 \text{ Ac.}$$

Most of the beach owners estimated that these densities were below the facilities' limits (Cohee 1970). Thus, the inland, commercial beaches may offer more of the services such as toilets, bathhouses, restaurants, etc., which attract recreational beach users. In turn, the ability of these inland facilities to attract customers may also mean that the increased use of coastal beaches, which the IGLLB projects, may be limited by inadequate supplies of ancillary services.

The IGLLB's assumptions concerning water quality also merit attention. Since Great Lakes water quality will improve, the IGLLB assumed all beaches described as polluted in the 1967 beach survey would be of "good" quality by 2022. Water quality along the Milwaukee County coastline has improved since approximately 1970, resulting in greater use of the beaches (Heipel 1975). Although runoff and sewer overflow during storms continue to require temporary closing of beaches near Milwaukee because of high bacteria counts, the IGLLB's assumptions about water quality appear to be valid. It should be remembered that swimmers, more so than fishermen or boaters, are likely to vary their locational preferences if the water has a foul odor or excessive turbidity (Ditton and Goodale 1973). Although the IGLLB's predictions of better water quality may be realized, use of this assumption and those on future demand for coastal beaches may overstate the benefits accruing from the regulation plans.

2. The IGLLB Procedure for Calculating the Economic Effect of a Regulation Plan on Beaches

To evaluate the impact of different regulation plans upon recreation beaches the IGLLB compared the seasonal value of a beach under Basis-of-Comparison levels with its value under a regulation plan. If a plan exposes more beach area by lowering the lake levels during the summer, the value of the larger area to beach users is a benefit from the plan. For the analysis of United States beaches the IGLLB assumed that the maximum benefit for a lake would occur at the water level which is exceeded 85% of the time. At this contour the value of additional beach area exposed equals the decline in value caused by exposure of undesirable features (IGLLB 1973, Appendix D, p. D-140).

The economic impact of regulation on swimming beaches is a function of (a) addition or subtraction of total beach area due to regulation, (b) user day values related to beach and water quality, and (c) intensity of beach use.

For every public and private beach surveyed in 1967, the IGLLB employed the following sequence of steps to calculate the differences in beach value under various regulation plans (IGLLB 1973, Appendix D, pp. D-131-132).

- (a) *Length of Normally Used Beach* — Derived by taking the information from the field form and converting the mileage figure recorded for the reach of beach to linear feet (this was obtained by actual measurement in some cases).
- (b) *Beach Area in Square Feet* — The recorded length was multiplied by the width to determine the number of square feet of usable beach (user carrying capacity). At the time of the survey the water levels of Lakes Superior and Michigan were 601.0' and 578.1-578.5', respectively.

- (c) *Beach User Density Categories* — High density—100 square feet per user; Medium density—500 square feet per user; Low density—1,000 square feet per user.
- (d) *Beach Carrying Capacity* — Determined by dividing the beach area by a beach density factor.
- (e) *Turnover Multiplier* — Assumes that on some beaches the same beach space is used by more than one beach user each day.
- (f) *Daily Attendance Potential* — Multiplying the beach carrying capacity by the turnover multiplier (i.e., $10,930 \times 2 = 21,860$). The effects of varying the turnover rate, which the IGLLB assumed to be two, is discussed below.
- (g) *Recreation Season Weekday Attendance* — Extends from June 1 through September 30. The weekdays minus weekends and holidays total 86 days. However, the 86 days were reduced by 20% to allow for adverse weather ($86 \text{ days} \times 0.8 = 69 \text{ weekdays}$).
- (h) *Weekday Capability Utilization* — One-third of the beach's daily attendance potential would be used on weekdays during the recreation season.
- (i) *Potential Seasonal Weekday Attendance* — Daily attendance potential (step f) multiplied by the weekday availability—69 days (step g). The total is then multiplied by the weekday capability utilization (33% of daily attendance potential) (step h).
- (j) *Recreation Season Weekend and Holiday Availability* — The weekends and holidays during the recreation season total 36 days. However, the 36 days were reduced by 20% to allow for adverse weather ($36 \times 0.8 = 29 \text{ days}$).
- (k) *Weekend and Holiday Capability Utilization* — Full utilization (100%) of the daily attendance potential would be used on the weekends and holidays.
- (l) *Potential Seasonal Weekend and Holiday Attendance* — Daily attendance potential multiplied by the weekend and holiday capability utilization (100%) (step f \times step j \times step k).
- (m) *Potential Season Attendance* — Derived by adding the potential weekday attendance (step i) with the potential weekend and holiday attendance (step l).
- (n) *Beach Quality Rating* — Determined from the field data collection procedure.
- (o) *Average User Day Value* — A monetary value assigned to individual beaches based on quality. A higher rated beach received a higher user day value than a lower quality beach. The values are given on the next page.

Value Per User-Day*

<u>Beach Quality</u>	<u>Canadian</u>	<u>U.S.</u>
A	\$2.00**	\$1.00
B	Not evaluated	.85
C	No comparable category	.70
D	No comparable category	.55
E	No comparable category	zero

Beaches closed due to pollution were given an "E" rating. When water quality is improved, these beaches will be reopened and heavily used due to their proximity to metropolitan areas. In this situation, total values for each regulation plan would be affected.

- (p) *Unweighted Unregulated Seasonal Value* — Potential seasonal attendance (step m) multiplied by the average day use value (step o), recorded in monetary terms.
- (q) *Unregulated Water Level Duration* — The duration at various water levels represented by a percentage factor. In the United States' evaluation the maximum beach value would occur at the water level which is exceeded 85% of the time. The Canadians used the water level which is surpassed 95% of the time.
- (r) *Unregulated Weighted Seasonal Values* — The unweighted, unregulated seasonal value (step p) multiplied by the percentage factor for each water level duration (step q).
- (s) *Regulated Water Level Duration* — The duration at various water levels represented by a percentage factor.
- (t) *Regulated Weighted Seasonal Value* — The unweighted, unregulated seasonal value (step p) multiplied by the percentage factor for each regulation water level duration (step s).
- (u) *Distribution of Primary User Intensity* — Allocated as follows—June 15%, July 40%, August 40%, September 5%.

* Beach values in the United States were estimated on the basis of user day values as outlined in Senate Document #97, (87th Congress, 2nd Session) Supplement No. 1, June 4, 1964, Washington, D.C. Beach values in Canada were based on user day values provided by the Department of Lands and Forests of Ontario, and the Department of Natural Resources of Quebec. The Canadian value includes a turnover factor and represents the daily value rather than the value per participant. The United States value considers turnover in a later step of evaluation.

** Demand is only on high-quality public beaches.

As with the assumption concerning demand, changes in factors such as the beach density factor or turnover multiplier can vary the results. The high intensity use value of 100 square feet per swimmer is substantiated by the Wisconsin Outdoor Recreation Plan—1972, which used a value of 105. However, this same Wisconsin study used a turnover factor of three in comparison to the IGLLB which incorporated a value of two. Possibly the daily turnover rate at beaches along Lake Superior and the northern part of Lake Michigan is greater than two people per day because of the colder waters. Any increase in the turnover rate directly increases the projected economic impact of raising or lowering summer water levels. Conversely, if beach carrying capacity rates are greater than the IGLLB estimates (for example, 200 square feet rather than 100 square feet per person at Terry Andrae State Park), the economic benefits from fewer extremely high water level periods on Lake Michigan will be reduced.

Throughout the recreational analysis the IGLLB assumed that a reduction in the range of levels was not detrimental to beaches. Beaches, however, are a dynamic system that have developed under a wide range of conditions. They are maintained by disturbance either by wave action or by wind. A reduction of lake levels will expose more beach area in the short term but may be harmful in the long term. In an area where disturbance is limited, encroachment of vegetation will occur which will reduce the area of exposed beach. Another consequence of a reduction in fluctuations will be in the profile of the beach. For example, fluctuations are beneficial in that they help to disperse sand and gravel evenly throughout the beach. The cleansing associated with fluctuation is vital in maintaining the quality of a beach.

In summary, the IGLLB appears to have carefully calculated the economic effect of regulation plans by employing the assumptions and method described in this paper. As noted below, the IGLLB's method of projecting the effect on beach use of different water levels is highly sensitive to changes of less than one inch. Although the IGLLB may have overestimated the impact of further regulation by assuming large increases in recreational beach use, the user day method of calculating recreation value may not fully express the benefits to the regional economy from purchases of goods and services (Ditton and Goodale 1973).

3. Evaluation of the Impact of Different Regulation Plans

The various proposed regulatory plans produce small differences in summer water levels on Lake Michigan relative to BOC conditions. However, even though the differences in levels are minimal the projected benefits to recreation are quite significant (Tables 9, 11).

Table 11 illustrates that for the months June-September the mean monthly levels (1900-1973) under SO-901, SEO-42P, Mod 7, and Mod 8 do not vary more than 0.10 feet from BOC on Lake Michigan. During extremely high supply years the maximum difference between SO-901 and BOC for any summer month would have been 0.45 feet (University of Wisconsin, Water Resources Management Program 1975, SO-901 vs BOC Michigan-Huron Means). The maximum difference in summer monthly mean levels between SEO-42P and SO-901 on Lake Michigan was 0.13 feet during the 1900-1973 Basis-of-Comparison period. Therefore, the maximum benefit to recreation beaches from Plans SO-901 or SEO-17P occurs when the levels are naturally high.

TABLE 11 COMPARISON OF SUMMER MONTHLY MEAN WATER LEVELS OF LAKE MICHIGAN (1900-1973) UNDER BOC CONDITIONS AND FIVE REGULATION PLANS

Month	BOC	SEO-42P SEO-17P*	SO-901	Mod 7	Mod 8
June	578.43	-.09	+.01	+.02	+.02
July	578.55	-.09	--	+.01	+.02
August	578.50	-.10	--	+.01	+.01
September	578.34	-.09	+.01	--	+.02

Source: University of Wisconsin, Water Resources Management Program 1975.

* Although similar information on levels under SEO-17P is not available, the summer water levels under this plan would be nearly equal to those under SEO-42P.

Although the differences in Lake Michigan mean summer levels under SEO-17P and SO-901 are small, Plan SEO-17P would create for Wisconsin about five more acres of recreational beaches than SO-901. This increased beach area could theoretically support about a maximum of 4,300 people on a summer day.** Using the IGLLB method and assumptions, projected benefits to recreational beaches increase rapidly with a small lowering of the water level.

Although several of the IGLLB assumptions concerning increased demand for beaches, turnover factors, or other variables may be questioned, the IGLLB presented a thorough and consistent attempt to place an economic value upon an amenity which is not readily measured. The public gains from the increased beach acreage not only through its value as a recreation resource, but also because beaches protect the bluff and backshore environment from wave attack. Doubt concerning the accuracy of the IGLLB projections does not appreciably diminish the relevance of using these figures to compare regulation plans, but the considerations noted in this working paper indicate that the recreation benefits calculated for SO-901 and SEO-17P may be overstated.

B. RECREATIONAL BOATING

Plans SO-901 and SEO-17P would probably enhance recreational boating opportunities on Lakes Michigan and Superior. The IGLLB analysis, however, found no measurable economic effect on boating. Although this conclusion may be correct, the IGLLB evaluation incorporates several questionable premises. An outline of the IGLLB method is presented below followed by a discussion of its assumptions and the possible consequences of new regulation plans for recreational boating in Wisconsin.

** Using an approximate beach slope of 5% which was obtained from the Bureau of Outdoor Recreation (IGLLB) field sheets, the maximum effect of a 0.15 foot reduction in levels along Wisconsin's 13.46 miles of public beaches is approximately 5 acres. All beaches were classified as high density (100 ft²/person) experiencing a turnover rate of two people per day.

The IGLLB method of evaluating the effect of lake level regulation on recreational boating consisted of the following steps:

- (1) Surveys were made of the number and types of recreational boats used on the Great Lakes—five classes were identified. Owners of boats which can be launched without a dock or trailered to another launching area would not suffer measurable economic losses from regulation (IGLLB 1973, Appendix D, p. D-160).
- (2) Estimates of the average depreciated dollar value of the boats in each of the five classes were made. From this figure the IGLLB estimated an average annual value of a season's use using 10% of the depreciated value. Division of this latter figure yielded the average value of a use day for each boat class (IGLLB 1973, Appendix D, p. D-162).
- (3) The IGLLB assumed an average lake level; levels above this point, the IGLLB contended, would not affect boating, while levels below this point would reduce the opportunities for boating (IGLLB 1973, Appendix D, p. D-162). The IGLLB did not adequately explain why they chose an average lake level that apparently was not the same as the BOC mean lake level during the recreational boating season, June through September (IGLLB 1973, Appendix D, p. D-162).
- (4) The IGLLB determined that there were approximately 40 days of possible boat use (June-September). This figure equals the number of weekends (14) times two days, plus three holidays and twenty vacation days, minus adverse weather or other distractions (IGLLB 1973, Appendix D, pp. D-162-163).
- (5) The IGLLB calculated the frequency of levels below the "average lake level" with stage-duration curves. For Lake Michigan the IGLLB addressed those periods when the levels were below 577.8 feet IGLD. As mentioned above in (3), the IGLLB appears to have arbitrarily chosen these levels; a comparable stage for Lake Superior was not given.
- (6) The IGLLB also assumed that "a plan would have to change the monthly mean level in the order of 0.5 feet or greater before having any economic measurable effect on recreational boating" (IGLLB 1973, Appendix D, p. D-163). It is unclear whether the IGLLB is referring to individual monthly means (June-September) over the BOC regime, the IGLLB's own assumed "average lake level," or the average of the mean monthly levels during the summer.

Several questions arise concerning these assumptions. First, the IGLLB's conclusion that Plan SO-901 does not change the mean monthly level more than 0.5 feet is not correct. On Lake Superior mean summer monthly levels under SO-901 would have exceeded BOC levels by more than 0.5 feet in seven years (1900-1973). Lake Superior summer levels according to SO-901 would have been below BOC levels by more than 0.5 feet in nine years (1900-1973) (University of Wisconsin, Water Resources Management Workshop, Computer Program SO-901 vs. BOC Superior Means). On Lake Michigan, however, Plan SO-901 does not alter the mean monthly levels during the boating season by more than 0.45 feet (University of Wisconsin, Water Resources Management Workshop, Computer Program SO-901 vs. BOC Michigan-Huron Means). Despite this problem of understanding how the IGLLB used the 0.5 foot criterion and the choice of an "average lake level," the conclusion reached by IGLLB that SO-901 would not have a measurable economic impact on boating is probably valid. As discussed below, however, plans SO-901 and SEO-17P would reduce the possible range of lake levels which the boater would experience.

Plans SO-901 and SEO-17P will probably improve boating opportunities on Lake Michigan because both plans raise the minimum summer levels that would occur under BOC conditions by approximately 0.25-0.45 feet. At the same time the plans lower the maximum levels by 0.4-0.6 feet which would occur under the Basis-of-Comparison. For the boat owner or marina operator this reduction in the range of lake levels facilitates access in dry periods and reduces dock construction costs, dredging, and possible flooding damages.

On Lake Superior the effects of either SO-901 or SEO-17P are more difficult to estimate. Plan SO-901 would eliminate the extremely low summer levels (598.82-599.51 IGLD) experienced under the BOC plan. This plan, however, actually slightly increases the number of times the levels are below 600 feet in June, while for July-September SO-901 reduces the frequency of levels below 600 feet (University of Wisconsin, Water Resources Management Workshop, Computer Program SO-901 vs. BOC Lake Superior Means, June-September). Because the difference between Lake Superior levels under SEO-17P vs. SO-901 will almost always be less than 0.10 feet, the plans would have very similar impacts upon boating.

If SO-901 and SEO-17P hamper recreational boating on Lake Superior, it will probably occur during high water level periods. SO-901 does not appreciably increase the number of times the levels exceed the BOC monthly mean (June-September) but during high water level periods, such as August 1973, SO-901 would raise the level of Lake Superior 0.90 feet over the BOC regulation plan given identical net basin supply sequences (University of Wisconsin, Water Resources Management Workshop, Computer Program SO-901 vs. BOC Lake Superior). Plans SO-901 and SEO-42P, however, do increase the frequency of occurrence of levels above 601 feet as shown in Table 12.

TABLE 12 NUMBER OF TIMES THE LEVELS OF LAKE SUPERIOR EXCEED 601 FEET
UNDER SO-901, SEO-42P, AND BOC

	<u>June</u>	<u>July</u>	<u>August</u>	<u>September</u>
SO-901	17	30	35	34
SEO-42P	13	27	34	34
BOC	10	19	22	25

Source: University of Wisconsin, Water Resources Management 1975.

Note: The levels under SEO-42P approximate fairly closely those which would occur under regulation plan SEO-17P.

In conclusion, the IGLLB probably was correct in concluding that plan SO-901 would not have a measurable economic impact on boating. The proposed plans, SO-901 and SEO-17P will reduce the number of extremely low levels on Lake Superior and Michigan, and also reduce the likelihood of very high levels on Lake Michigan. Higher lake levels on Lake Superior will hamper recreational boating if private docks and piers are not constructed to accommodate the natural fluctuation of that lake.

IV. CONCLUSIONS

Given the current state of knowledge about the prediction of lake levels and associated shore damages, the IGLLB method is careful and consistent. However, because information on shore damage is so scarce and general, the IGLLB estimates provide at best a very general indication of possible shore losses under various regulation plans and not an accurate, quantitative analysis. The following outline points out major problem areas in the IGLLB method.

A. UNCERTAINTY DUE TO THE RANGE OF POSSIBLE FUTURE NET BASIN SUPPLIES

Ten simulated supply sequences in the Main Report (p. 136) indicate possible damages from SO-901 ranging between \$100,000 and \$2,300,000 on Lake Superior, while on Lake Michigan the same plan yields possible benefits ranging from \$300,000 to \$1,000,000. Four of the ten sequences indicate that shore benefits on Lakes Michigan and Huron do not exceed the losses on Lake Superior. The actual economic effect of SO-901 may be within these ranges depending upon the actual sequence of net basin supplies which occur. In order to adequately assess the possible effects of other regulation plans, these plans should also be evaluated under alternative simulated net basin supplies.

B. UNCERTAINTY IN METHOD FOR CALCULATING DAMAGES FROM EROSION AND INUNDATION

All U.S. damages are based on a damage record of only one year (1951-1952) and on an assumed relationship between lake level and damage. The IGLLB provides inadequate evidence to confirm the curvilinear function used to define this relationship.

More recent economic projections of future property values in Wisconsin are 10 to 50% lower than the 1968 estimates used by the IGLLB. Although the net effect of these lower estimates will be discounted heavily, the benefits of regulation to Lake Michigan shorelands will be less than the IGLLB indicates.

The index of change in value of residential damages is a major determinant of damages, particularly in the urban reaches. Some questionable assumptions made by the IGLLB can affect this index.

- The IGLLB assumes that land development patterns continue as they have in the past, although Wisconsin's Water Resources Act and the National Flood Insurance Program have already established more strict control on shore development. However, when assumptions on the effect of future land use controls are altered, the IGLLB method indicates only slight changes in projected damages.
- A major questionable assumption is that protected shoreline will incur no further damage once a protective work is constructed.

The IGLLB assumption that ultimate water level reflects the storm intensity within a month is not adequately documented. The frequency of storm events within months over a number of years should be studied.

There are some biases in the IGLLB method which tend to overestimate the benefits of regulation.

- The IGLLB assumes that all shore damages are caused by lake level effects and does not differentiate those erosive factors (e.g., surface runoff, groundwater seepage, raindrop impact, frost action) which will continue to occur in spite of regulation.
- In calculating ultimate water level (damaging capacity), the IGLLB overestimates the benefits from reducing mean monthly levels and overestimates the damages from raising mean monthly levels.

Since the effect of regulation on most lakes is to reduce mean monthly levels, overall damages under regulation plans are probably underestimated. This bias results from use of an inadequate definition of breaking depth in the ultimate water level calculation.

C. RECREATION

Recreation benefits are a major component of the shore property benefits resulting from proposed regulation plans. For example, under SO-901, \$228,000 of \$803,000 (28%) of the average annual benefits to shore property are due to increased beach acreage; under SEO-42P \$2,176,000 of the projected \$8,156,000 (27%) of total benefits are attributable to recreation. Calculation of these benefits is extremely sensitive to small changes in mean monthly levels. For example, Lake Michigan recreation beaches benefit by \$82,000 under SO-901 and by \$850,000 under SEO-42P while the difference in mean monthly water levels between these two plans never exceeds 0.14 feet.

APPENDIX A

SAMPLE CALCULATIONS OF ULTIMATE WATER LEVELS

CALCULATION A — IGLLB method for calculating ultimate water levels.

X_1 = recorded monthly mean lake level

SWL = recorded storm water level, maximum instantaneous level

X_3 = Basis-of-Comparison monthly mean lake level

X_4 = Basis-of-Comparison storm water level

where $X_4 = X_3 + SWL - X_1$

d_b = depth of water at breaking

where $d_b = SWL - LWD$ (Low Water Datum) (4)

H_b = wave height at breaking

where $H_b = \frac{d_b}{1.28}$ (3)

H'_0 = deep water wave height derived from Figure 4

T = deep water wave period derived from Figure 4

H = wave height used to compute runup, the lower of H_b or H'_0

m = representative beach slope

R_u = wave runup

where $R_u = 2.3mTH^{0.5}$ (2)

UWL = ultimate water level

where $UWL = SWL + R_u$ (1)

Same calculations for Reach 7004, March 1972 through February 1973 are tabulated in Figure 5.

CALCULATION B — Demonstration of range in runup (and ultimate water level) due to 20% error in wave period inherent in the IGLLB method.

For November 1972, on Reach 7004, where

$$H_b = H = 3.80 \text{ feet}$$

$$m = 0.083$$

$$T = 7.0 \text{ sec.}$$

Using Equation 2

$$R_u = 2.3 (0.083) (7) (3.8)^{0.5} = 2.61 \text{ feet}$$

Using $\pm 20\%$ error in T

$$R_u = 2.3 (0.083) (7.7) (3.8)^{0.5} = 2.87 \text{ feet}$$

$$R_u = 2.3 (0.083) (6.3) (3.8)^{0.5} = \frac{2.35 \text{ feet}}{0.52 \text{ foot range}}$$

CALCULATION C — Demonstration of underestimation of breaker height, H, and therefore ultimate water level for lowered lake levels, by IGLLB method.

For November 1972 and 1967, on Reach 7004, where

$$\text{SWL} = \text{recorded monthly mean lake level} + \text{storm setup} \quad (5)$$

Storm setup is calculated for the November 1972 storm and then this value is applied to the November 1967 mean. Hence, we are dealing with the same storm, which should produce the same wave height at breaking, H_b (assuming smooth nearshore bottom slope).

Using Equation 4

$$d_b = 581.36 - 576.8 = 4.56 \text{ for November 1972}$$

$$d_b = 579.24 - 576.8 = 2.44 \text{ for November 1967}$$

Using Equation 3

$$H_b = \frac{4.56}{1.28} = 3.56 \text{ for November 1972}$$

$$H_b = \frac{2.44}{1.28} = 1.9 \text{ for November 1967}$$

And in the runup equation (2)

$$R_u = 2.3 (0.083) (7) (3.56)^{0.5} = 2.52 \text{ for November 1972}$$

$$R_u = 2.3 (0.083) (7) (1.9)^{0.5} = \frac{1.84}{0.68 \text{ difference}} \text{ for November 1967}$$

Runup difference of 0.68 ft. for the same storm.

CALCULATION D — Demonstration of error in IGLLB method for calculation of maximum breaker height, H_b .

From wind data taken at 3-hour intervals at Mitchell Field, Milwaukee.

Average wind speed times 1.2	= 28 knots
Duration	= 12 hours
Average direction	= 35 degrees (northeast)
Equivalent fetch	= 95 miles

For these conditions in Figure 2

$$H'_0 = 10.0 \text{ ft.}$$

$$T^0 = 7.0 \text{ sec.}$$

Using Figure 4, where

$$\frac{H'_0}{gT^2} = .00634, \text{ then}$$

$$\frac{H_b}{H'_0} = 1.04, \text{ and}$$

$$H_b = 10.40 \text{ ft.}$$

Whereas, in Equation (3)

$$H_b = 3.8 \text{ ft.}$$

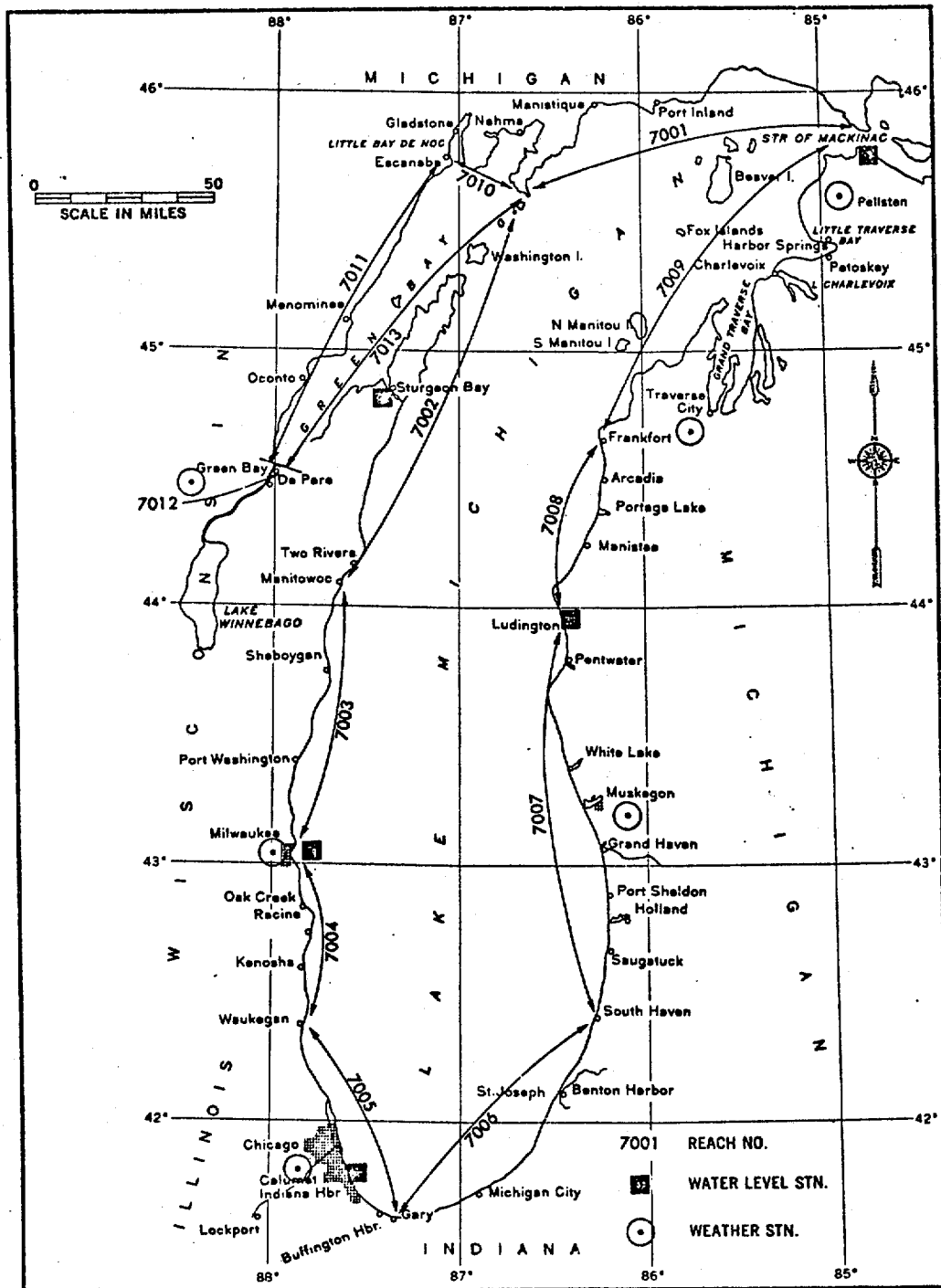
which is 275% too low.

More sample calculations of this type are tabulated in Table 16.

TABLE 13 SYMBOLS USED IN THE CALCULATIONS OF ULTIMATE WATER LEVELS

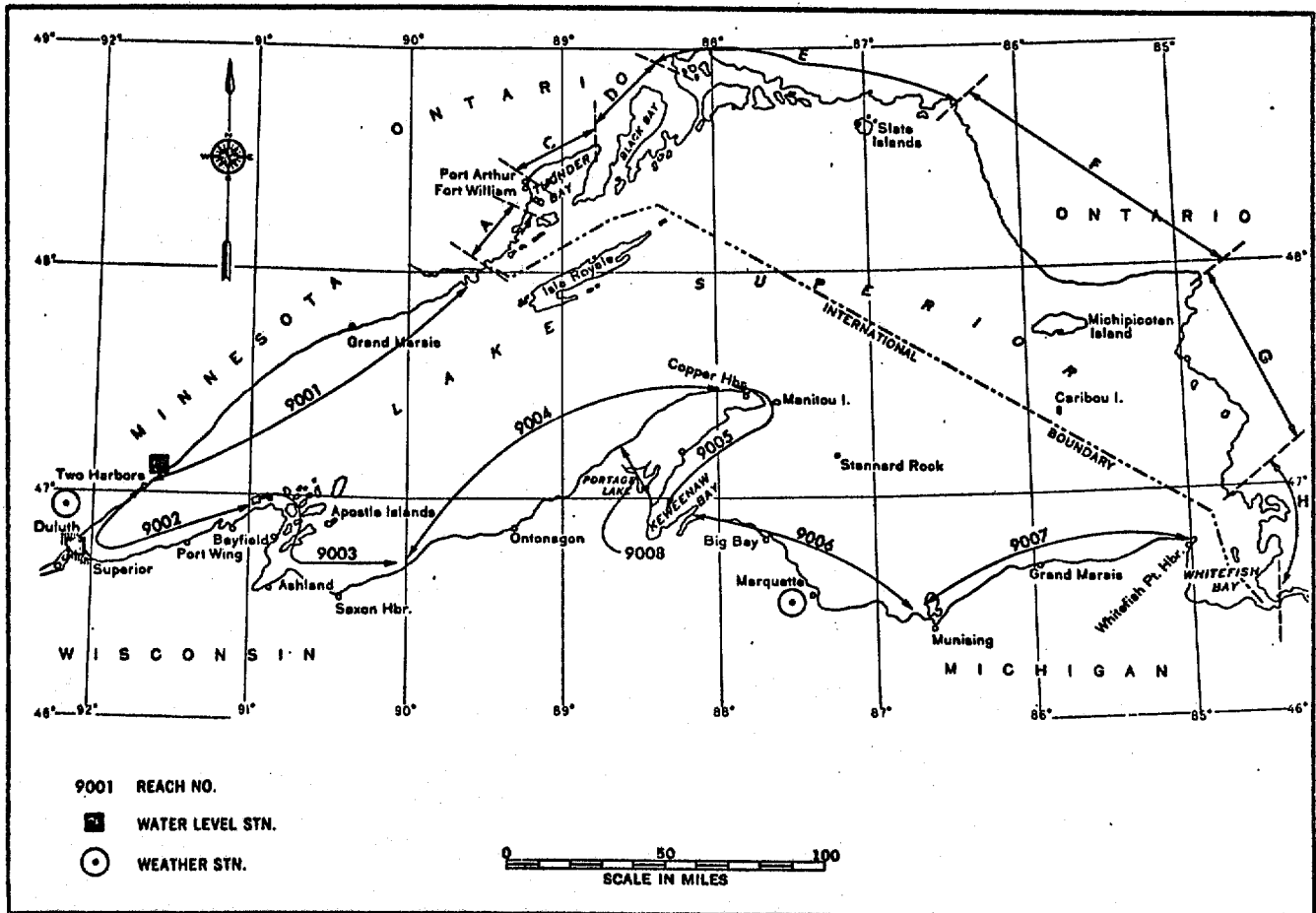
d_b	depth of breaking, where a wave breaks
H	wave height in the runup equation, the lower of either H_b or H'_0
H_b	maximum wave height at breaking
H'_0	deep water wave height
IGLD	a zero elevation point for the Great Lakes, very near mean sea level
LWD	low water datum, an elevation above IGLD for each lake
m	representative beach slope
R_u	wave runup
SWL	storm water level
T	wave period
UWL	ultimate water level

FIGURE 7 LAKE MICHIGAN LOCATION MAP



Source: IGLLB 1973, Appendix C, p. C-30.

FIGURE 8 LAKE SUPERIOR LOCATION MAP



Source: IGLLB 1973, Appendix C, p. C-31.

TABLE 14 UNDIKED AND DIKED REPRESENTATIVE SLOPES AND EQUIVALENT FETCHES IN MILES

UNDIKED AND DIKED REPRESENTATIVE SLOPES			EQUIVALENT FETCHES IN MILES							
Reach No.	Representative Slope		Wind Directions							
	Undiked	Diked	N	NE	E	SE	S	SW	W	NW
2001	0.100	0.200	38	53	42	0	0	0	26	38
2002	0.050	0.200	44	50	42	0	0	0	23	49
2003	0.125	0.200	36	23	9	0	0	42	66	62
2004	0.058	0.200	14	0	0	0	11	44	59	36
2005	0.111	0.200	0	0	0	18	37	47	26	6
3001	0.083	0.200	0	0	35	30	20	0	0	0
3002	0.071	0.200	30	30	20	0	0	0	0	15
3003	0.125	0.300	50	100	0	0	0	0	60	55
5001	0.062	0.200	0	0	52	80	51	25	21	0
5002	0.045	0.200	31	42	59	50	0	0	17	25
5003	0.020	0.200	61	77	82	73	40	10	0	12
5004	0.026	0.200	29	69	52	13	19	20	10	0
5005	0.042	0.200	63	80	46	0	0	16	22	23
5006	0.167	0.200	93	69	36	31	26	0	0	39
7001	0.100	0.200	0	0	34	39	101	93	24	7
7002	0.091	0.200	36	75	68	87	113	58	0	0
7003	0.100	0.200	79	86	73	74	72	19	0	0
7004	0.083	0.200	103	93	62	50	35	0	0	20
7005	0.058	0.200	109	95	35	15	0	0	0	53
7006	0.143	0.200	88	49	17	0	25	32	39	64
7007	0.200	0.200	72	0	0	0	51	70	72	73
7008	0.333	0.333	64	23	0	0	69	80	56	57
7009	0.200	0.200	36	25	20	0	0	40	48	43
7010	0.067	0.200	0	10	17	18	30	29	10	7
7011	0.100	0.200	23	28	23	13	19	20	0	0
7012	0.111	0.200	29	32	0	0	0	0	0	0
7013	0.125	0.200	23	32	0	0	13	23	18	14
9001	0.250	0.250	0	45	84	84	67	50	25	0
9002	0.333	0.333	11	71	68	10	0	0	0	0
9003	0.33	0.333	69	106	91	27	13	0	0	0
9004	0.062	0.333	92	100	27	0	0	22	62	72
9005	0.143	0.333	0	98	111	62	23	16	0	0
9006	0.091	0.333	99	113	62	15	0	0	0	70
9007	0.167	0.333	121	77	57	0	0	14	77	129

Source: Great Lakes Basin Commission 1975. Appendix 11, pp. 94-95.

TABLE 15 VARIANCE (S^2) OF DAILY LAKE LEVELS ABOUT THEIR MONTHLY MEAN—MILWAUKEE

$$S^2 = \frac{\sum_{i=1}^n (x_i - \bar{x})^2}{n-1}$$

Month	S^2	Month	S^2
January	.0486	July	.0068
February	.0338	August	.0099
March	.0304	September	.0130
April	.0609	October	.0516
May	.0351	November	.0320
June	.0033	December	.0610

Source: U.S. Department of Commerce 1972 and 1973, Great Lakes Levels.

TABLE 16 ULTIMATE WATER LEVELS FOR REACH 7004, MARCH 1972-FEBRUARY 1973

IGLLB Method												
	March, 1972	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan, 1973	Feb.
x_1	579.09	579.35	579.82	579.94	580.05	580.29	580.30	580.14	580.14	579.96	579.93	580.07
SWL	580.07	580.08	580.16	580.75	580.45	580.87	580.94	581.21	581.02	580.94	580.67	580.71
Day/Time of SWL	1/2200	22/1900	30/0300	10/1200	18/0500	20/0100	18/0700	23/1300	14/0600	30/1800	21/2000	15/1100
x_3	579.38	579.66	580.04	580.27	580.44	580.65	580.74	580.62	580.48	580.40	580.40	580.37
x_4	580.36	580.39	580.38	581.08	580.84	581.23	581.38	581.69	581.36	581.38	581.74	581.01
d_b	3.86	3.89	3.88	4.58	4.34	4.73	4.88	5.19	4.86	4.88	5.24	4.51
H_b	3.02	3.04	3.03	3.58	3.39	3.70	3.81	4.05	3.80	3.81	4.09	3.42
Avg. Speed (Knots)	17	19	17	24	12	20	14	19	28	14	17	24
Duration (Hrs)	7	19	3	33	5	1	1	13	12	3	17	23
Avg. Direction	360	250	50	10	230	140	160	340	35	180	100	350
Equiv. Fetch (Mi.)	103	0	90	100	0	15	5	65	95	0	30	95
H'_0	3.5	1.1	2.5	8.0	0.5	1.75	1.1	5.25	10.0	0.75	3.3	7.8
T_0	4.25	2.2	3.4	6.25	1.5	2.75	2.2	5.1	7.0	1.75	4.0	6.2
H	3.02	1.1	2.5	3.58	0.5	1.75	1.1	4.05	3.80	0.75	3.3	3.52
m	0.083	0.083	0.083	0.083	0.083	0.083	0.083	0.083	0.083	0.083	0.083	0.083
R_u	1.41	0.44	1.03	1.99	0.20	0.69	0.44	1.73	2.61	0.29	1.39	1.97
UWL	581.77	580.83	581.43	583.07	581.04	581.92	581.82	583.42	583.97	581.67	583.13	582.98
Shore Protection Manual Method												
H'_0/gT^2	0.02558	.01553	.02284	.03975	.01035	.01976	.01553	.03197	.00634	.03106	.00641	.03907
H_b/H'_0	0.97	0.94	0.94	1.00	0.96	0.94	0.94	1.00	1.04	1.00	1.01	1.00
H_b	3.40	1.03	2.35	8.0	0.48	1.65	1.03	5.25	10.40	0.75	3.3	7.8
R_u	1.49	0.42	0.99	3.38	0.20	0.68	0.42	2.44	4.31	0.29	1.39	3.30
UWL	581.85	580.82	581.39	585.46	581.04	581.91	581.80	584.13	585.67	581.67	583.13	584.31
Difference	+0.07	-0.01	-0.04	+2.39	0	-0.01	-0.02	+0.71	+1.70	0	0	+1.33

Sources: Great Lakes Basin Commission 1975, Appendix 11, p. 95.
 U.S.—CERC 1973, Vol. 1, p. 3-20.
 U.S. Department of Commerce 1972 and 1973, Climatic Observations.
 U.S. Department of Commerce 1972 and 1973, Great Lakes Levels.

APPENDIX B

EVALUATION OF REGULATION PLANS THROUGH STAGE-DAMAGE CURVES

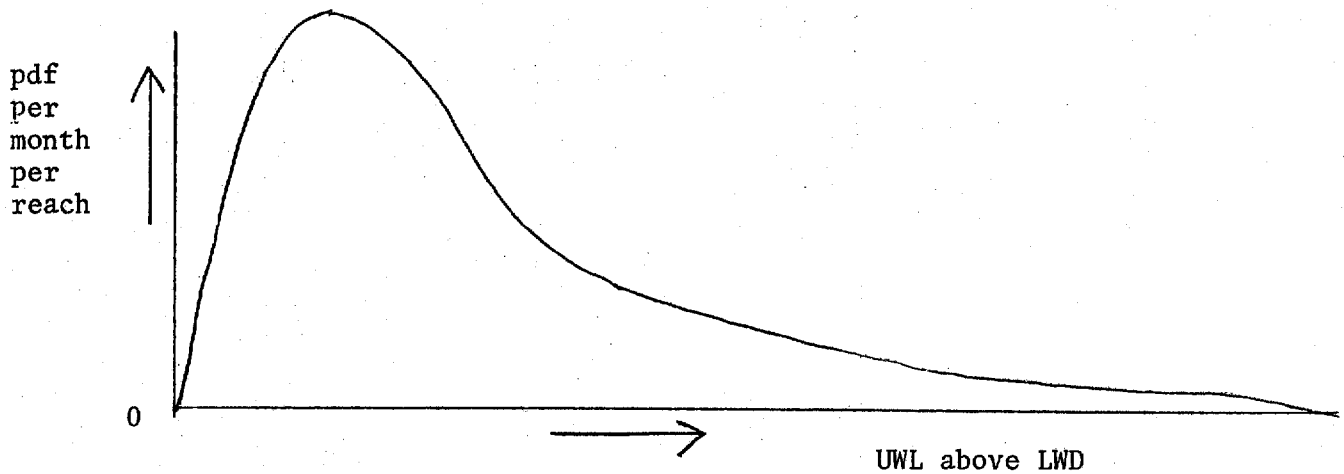
The method used in Appendix C to evaluate regulation plans conforms well with the standard benefit evaluation techniques for federal flood control projects. A brief, theoretical description of this technique, and a criticism of the method is presented here for clarification.

From the point of view of economic theory and method, the evaluation of water level regulation benefits involves several matters.

- A probabilistic element in the evaluation of a benefit is explicitly included in the method.
- A public good (in the rather strict sense) is evaluated by making certain assumptions about rational behavior on the part of beneficiaries. This means that once a regulation plan is accepted, the benefits attributable to that plan will accrue to all property owners on a given lake; i.e., no individual property owner can choose not to accept the benefit by not expressing a willingness to pay for it; for this type of public good benefit is not a market good. Furthermore, it is in the rational self interest of each property owner to not reveal a preference for the benefit because if one receives a benefit, all will. This argument does not apply to losses from a regulation plan because of the individual option to build protective structures.
- The matter of public information and how it is obtained becomes a central issue in developing evaluation methods.

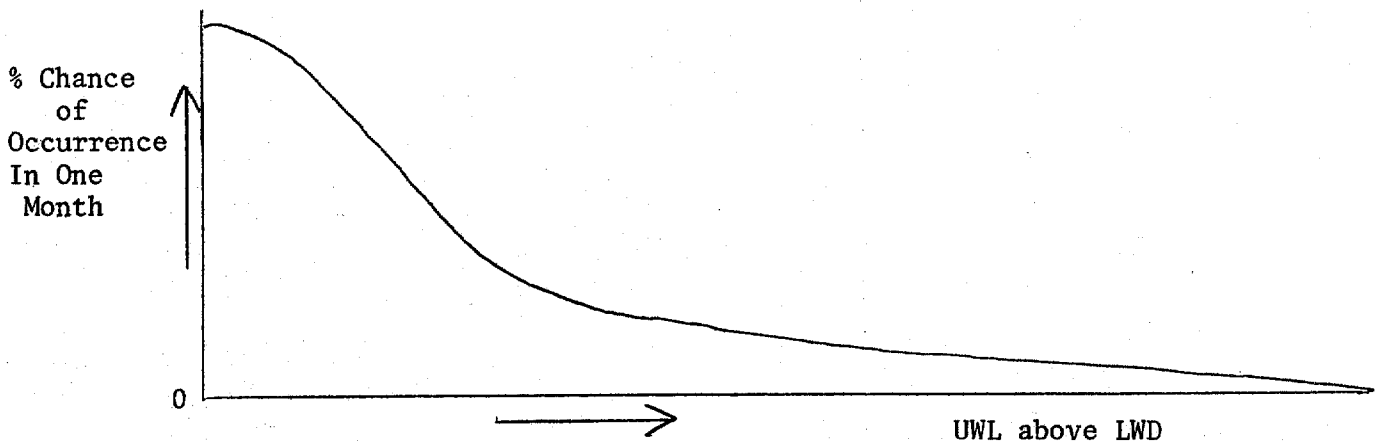
The evaluation of benefits from reducing mean water levels through regulation plans proceeds by the construction of a set of interrelated curves. Figure 9 shows a relative probability curve for ultimate water levels, expressing a given ultimate water level occurrence in one month as a function of the probability of its occurrence. Since the ultimate water levels in one month are a function of mean monthly water levels, storm set-up and wave run-up, the shape of the probability damage function (pdf) reflects the occurrence of storms within a month, which can be approximated by either the log normal or the Gamma (Pearson Type III) distribution. Each month of the year, for each reach, will have an associated pdf for ultimate water levels, reflecting the annual distribution of relatively stormy vs. calm months on the Great Lakes; i.e., each monthly distribution will have a different mean and standard deviation. A reasonably precise statistical estimation of the pdf depends on the availability of within month ultimate water level data for a long period of record. Frequency analyses are useless if the period does not represent the long-term frequency relationship. Ultimate water level frequency estimates become less reliable with shorter records, or with records which record only one ultimate water level for each month.

FIGURE 9 A RELATIVE PROBABILITY CURVE FOR ULTIMATE WATER LEVELS



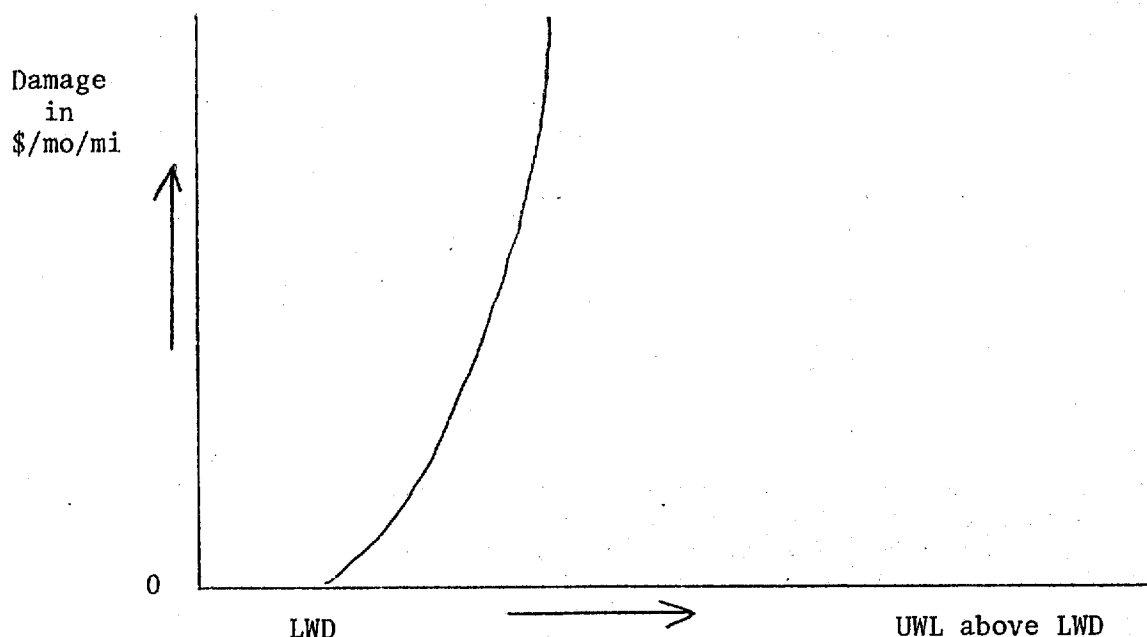
Once a monthly pdf for ultimate water levels is determined, one can derive a second relationship which shows the cumulative probability that the ultimate water level is at or above the low water datum (Figure 10).

FIGURE 10 CUMULATIVE PROBABILITY FOR ULTIMATE WATER LEVELS



The next step in the sequence involves the use of a stage-damage curve. Figure 11 shows a stage-damage curve for a given reach of shoreline and a given month. The assumption is made that at the moment when damage occurs, the long-term level of activities on the shoreline is the same, assuming that an equilibrium has been established between flooding and erosion and the level of economic activity on the shoreline.

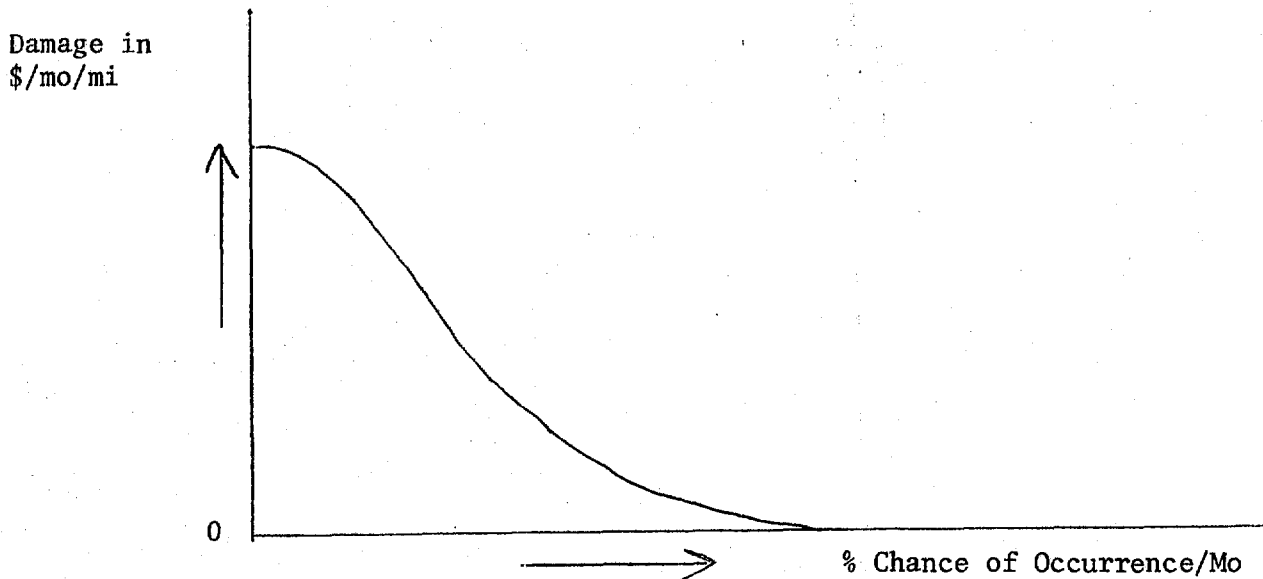
FIGURE 11 A STAGE-DAMAGE CURVE



The shape of the stage-damage curve in Figure 11 shows that for a 1% increase in the UWL, the proportionate increase in dollar damages is greater than 1%. Care must be taken in establishing this relationship because the shape of the stage-damage curve is critical to the final results. The shape of the curve in Figure 11 (given the others) depends on the distribution of activities on the shoreline.

The final curve in this technique is obtained by combining Figures 10 and 11 into Figure 12, which relates damage to percentage chance of occurrence.

FIGURE 12 RELATIONSHIP BETWEEN DAMAGES AND THE PERCENT CHANCE OF OCCURRENCE

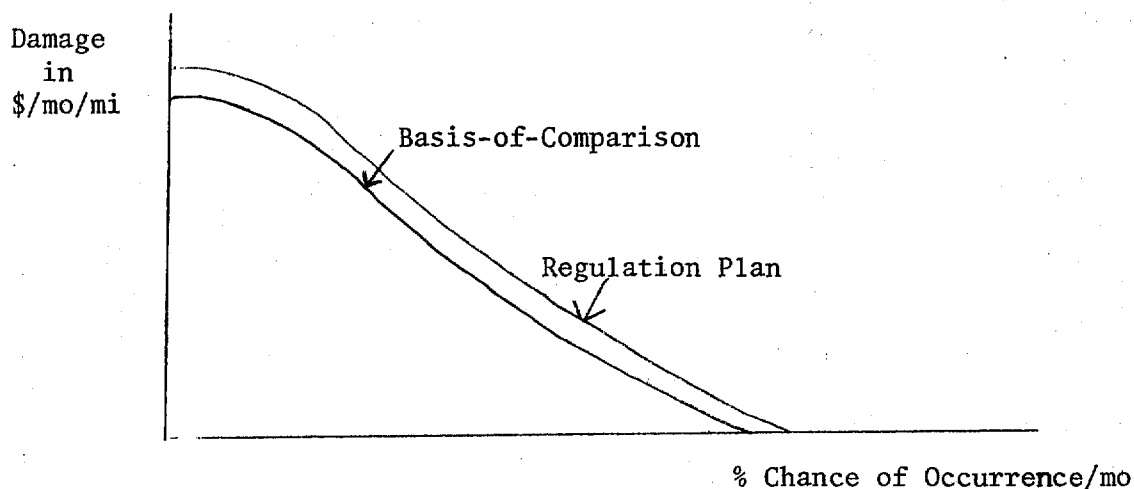


In accordance with usual statistical concepts, the area under the curve in Figure 12 is the expected value of damage or the mathematical expectation of damage. More formally, if f is the probability function, and x is a random variable representing damage, the expected value of damage/month/reach is:

$$\mu = \int_{-\infty}^{\infty} xf(x)dx$$

To obtain a benefit function (or the expected value of damages avoided function), the calculation proceeds as follows: The effect of an increase or decrease in mean monthly water levels on the probability of various ultimate water levels for a given month and reach is determined. Then this effect is traced through the other curves to the probability damage curve. The effect on this curve, if the monthly mean stage and variance are increased, is to shift the curve rightward as shown in Figure 13.

FIGURE 13 RELATIONSHIP BETWEEN DAMAGES AND THE PERCENT CHANCE OF OCCURRENCE



The integral of the new curve is determined, and the difference between the two integrals is taken as the expected value of the damages due to the regulation plan. If the regulation plan lowers the mean monthly stage and lowers the variance, the new probability damage curve will shift to the left. The difference between the integrals is then taken to be the benefit due to the regulation plan.

It is in this sense that the erosion and inundation damages are not determined explicitly as hard values in total, but rather as the most probable damages which result from a change in regulation. The sum of the differences in integrals, over all months and all reaches, reveals the net benefit or loss due to a change in water level regulation over all of the Great Lakes.

The basic rationale of this method, as associated with benefit-cost techniques, is that a fully informed shore property owner would be willing to pay up to the expected value of his losses in order to avoid them. Since protection of one property owner through water level regulation automatically provides a degree of protection for all others on the same reach, or even on the same lake, the demand or willingness to pay functions for all affected shore property occupants must be added vertically in the classic public goods style.

The main problem with this assumption about economic valuations of benefits or losses resulting from changes in water levels is the assumption that people make decisions based on expected values. There are three potential problems—all of them are real.

- For various reasons people may not find it reasonable to act on the basis of expected values of damage from erosion and flooding (for example, in decisions to occupy and engage in economic activity on the shoreline).
- Even if people are willing to act on this basis they almost never understand the concept or have the necessary information to do so.
- Since other decisions, occupance, protective structures, etc., are not based on expected values of damages, designing regulation plans on the basis of the expected value criteria will not lead to an optimal combination of measures to reduce shore erosion and flooding.

Mathematical expectation is a good decision rule when it is in fact true that risk can be pooled in some fashion. It represents the realized average value of the outcomes if there are many repetitions of the event. This situation is not characteristic of individuals or firms occupying the shoreline of the Great Lakes subject to erosion and flood hazard. A single extreme event may spell financial disaster so that the decisionmaker may be a risk averter. Or, some people may be unaware of the hazard, or have a propensity for risk, and therefore conduct short-term activities on the shoreline in hopes of reaping a gain before an extreme event occurs. Of course, the progression of shoreline erosion is not influenced by extreme events so much as by the steady, long-term action of normal wind and wave events, but the lack of information argument still applies (IGLLB 1973, Appendix C, pp. C-102-104). Such persons presumably would not be willing to pay up to the expected value of their losses to obtain protection through regulation. This would suggest that the expected value method results in an overestimation of benefits and losses.

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